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ABSTRACT

Investigated was the compatibility between the intellectual abilities of students and the level of intellectual operations required by secondary level physics textbooks. Student intellectual levels were determined for 949 tenth-, eleventh-, and twelfth-grade students by administration of Piagetian tasks. Major concepts presented in physics textbook chapters were classified as concrete or formal. Results indicated that 74% of physics students were at the formal level of operation and 40% of the potential physics students were at the formal level; all 130 major concepts analyzed from six physics textbooks required a formal level of operation. (SL)

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THE UNIVERSITY OF OKLAHOMA
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RELATIONSHIPS BETWEEN CONCRETE AND FORMAL OPERATIONAL PHYSICS CONCEPTS AND THE INTELLECTUAL LEVELS OF HIGH SCHOOL STUDENTS

A THESIS
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degree of
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A THESIS

APPROVED FOR THE DEPARTMENT OF EDUCATION

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RELATIONSHIPS BETWEEN CONCRETE AND FORMAL OPERATIONAL PHYSICS CONCEPTS AND THE INTELLECTUAL LEVELS OF HIGH SCHOOL STUDENTS

CHAPTER I

INTRODUCTION

Statement of the Problem

During the curriculum reform movement of the fifties and sixties, the objectives of many science curricula were to develop scientific literacy and to teach the structure of the discipline. It was believed that such learning experiences would enable students to guide their own future learning.

Emphasis in science teaching changed from concern with factual knowledge to learning concepts and intellectual processes. The student learned about science by behaving like a scientist in a laboratory. Experimentation became an integral part of science teaching. The anticipated revolution in science education, increase in enrollments and change in attitude towards science, however, did not occur. ". . . the curriculum reform movement has made a pitifully small impact on classroom practice."[1]

Silberman suggested that "they (developers in the curriculum reform movement) placed almost all their emphasis on subject matter, i.e., on creating 'great compositions;' and for the most part ignored the needs of the individual."[2] For learning to take place there must be a degree of compatibility between the intellectual abilities of the learner and the level of intellectual operations required to understand the subject matter. This study investigated the compatibility between the concepts presented in secondary school physics textbooks and the students and potential students of that discipline.

Previous research by Linda Johnson indicated that the operational level of high school biology students and the major biology concepts presented in a textbook to these high school students were incompatible.[3] Research by Anton Lawson showed that concrete operational students had success only with understanding concrete operational concepts, whereas formal operational students succeeded with concrete and formal operational concepts.[4]

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[1] Charles E. Silberman, "Crisis in the Classroom," in Curriculum: Quest for Relevance, 2nd Ed., edited by William Van Til (Boston: Houghton Mifflin Co., 1974), p. 102.

[2] *Ibid.*, p. 103.

[3] Linda M. Johnson, "Biology Concepts Taught Compared to the Intellectual Level of the Biology Student" (Unpublished M.Ed. thesis, The University of Oklahoma, 1975), p. 71.

There is, however, very little data on the intellectual level of development of high school students enrolled in physics and on the school population potentially eligible for enrollment, but not enrolled, in physics courses. There are no data available on the concepts presented in textbooks to students.

The two investigations described above and the lack of empirical data on high school physics students and textbooks suggested the research proposed. Specifically, answers to the following questions were sought:

a. What are the levels of intellectual development of students enrolled in high school physics courses in the State of Oklahoma?

b. What are the levels of intellectual development of students who are eligible for enrollment, but who have not enrolled, in high school physics courses in the State of Oklahoma?

c. What are the operational levels of physics concepts presented in physics textbooks used in the State of Oklahoma?

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[4] Anton E. Lawton, "Relationships Between Concrete and Formal Operational Science Subject Matter and the Intellectual Level of the Learner" (Unpublished Ph.D. dissertation, The University of Oklahoma, 1973), pp. 87-92.

d. What, if any, are the relationships between the above three questions?

The Purpose of the Study

The purposes of the study were to:

a. Determine the intellectual levels of students, as measured by specific Piagetian tasks,[5] enrolled in high school physics.

b. Determine the intellectual levels of students not enrolled, but eligible for enrollment, in high school physics courses.

c. Classify concepts in physics textbooks on the approved list for the State of Oklahoma using criteria developed by Lawson,[6] Bautista,[7] Piaget, and Inhelder.[8]

d. Compare the intellectual levels of students enrolled in physics courses with those students eligible for enrollment, but not enrolled in physics.

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[5] The specific tasks used in this research are described on pages 19 to 24.

[6] Lawson, pp. 4-6.

[7] Leticia B. Bautista, "The Relationship Between Intellectual Levels and Achievement in the Comprehension of Concepts Classified According to a Scheme Derived from the Piagetian Model" (Unpublished Ph.D. dissertation, The University of Oklahoma, 1974), pp. 26-31.

[8] Barbel Inhelder and Jean Piaget, The Growth of Logical Thinking from Childhood to Adolescence (New York: Basic Books, Inc., 1958), pp. 308-329.

e. Compare the intellectual levels of students enrolled in physics courses with the operational levels of physics concepts presented in textbooks.

f. Compare the intellectual levels of students eligible for enrollment, but not enrolled, in physics courses with the operational levels of physics concepts presented in textbooks.

Definitions

Piaget's theory of intellectual development[9] provided the theoretical framework in which to determine the intellectual levels of students and the classification scheme required for the physics concepts. The following definitions are taken from Piagetian theory.

a. Action. An action is a response of an individual whether it be "directed toward the outside world or as an act internalized in thought."[10] These responses are of a functional nature.

b. Operation. An operation is a mental action that can be internalized and is reversible. It can be carried out in thought as well as in action and it can take place in both directions.[11]

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[9] For an introduction to Piaget's theory of intellectual development, see Herbert Ginsburg and Sylvia Opper, Piaget's Theory of Intellectual Development - An Introduction (Englewood Cliffs, New Jersey: Prentice-Hall, 1969).

[10] Jean Piaget, Psychology of Intelligence (New Jersey: Littlefield. Adams and Co., 1973), p. 4.

c. Reversibility. Reversibility is "the permanent possibility of returning to the starting point."[12] After a particular mental action has been carried out in one direction, the original starting point has been achieved by performing the opposite action. This mental action is then reversible.

d. Inversion. Inversion is the process by which one returns to the starting point by cancelling an operation which has already been performed.[13]

e. Structure. A structure is a group of logically related operations.[14] Mental structures serve to guide mental operations.

f. Formal Operational Thinking. Formal operational thinking is characterized by the ability to use hypothetical reasoning based on the logic of all possible combinations and to perform controlled experiments.[15] One of the most fundamental properties of formal thought is the subordination of reality to possibility.

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[11] Jean Piaget, Genetic Epistemology (New York: W. W. Norton, 1971), pp. 21-22.

[12] Inhelder and Piaget, The Growth of Logical Thinking, p. 272.

[13] Ibid

[14] Bautista, p. 3.

[15] Inhelder and Piaget, The Growth of Logical Thinking, Translator's Introduction, p. (xiii).

g. Concrete Operational Thinking. Concrete operational thinking is based upon the use of what Piaget calls concrete operations. These mental operations are termed concrete "because they operate on objects and not yet in verbally expressed hypotheses. There are operations of classification, ordering . . . and all the fundamental operations of elementary logic of classes and relations."[16]

h. Concrete Operational Concepts. Concrete operational concepts are concepts whose meaning can be developed from first-hand experience with objects or events.[17] Examples are common objects such as pens, books, and leaves.

i. Formal Operational Concepts. "Formal operational concepts are concepts whose meaning is derived through position within a postulatory-deductive system."[18]

A formal concept, e.g., the photon, cannot be concretely experienced. Understanding of the concept of a photon is derived from a set of postulates dealing with the nature of light and energy.

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[16] Jean Piaget, "Development and Learning," Journal of Research in Science Teaching, 1964, No. 3, p. 177.

[17] Lawson, pp. 4-5.

[18] *Ibid.*, pp. 5-6.

Physical models do not represent formal concepts. A physical model can be built which indicates some of the components of the Bohr model of the atom. Complete comprehension of the Bohr model of the atom, however, requires understanding of a set of postulates related to electronic energy levels, atomic size and composition. For this understanding the student must be able to think logically in a hypothetico-deductive manner.

j. Classification. The subject arranges objects in collections according to the similarities and differences between the properties of the objects.[19]

k. One-to-One Correspondence. One-to-one correspondence operations involve the construction of equivalence between two separate orderings, these orderings containing equal numbers of elements.[20]

l. Seriation. "Seriation is the operation of ordering objects according to increasing or decreasing size" or any other property so that $A < B < C$.[21]

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[19] Jean Piaget and Barbel Inhelder, The Psychology of the Child (New York: Basic Books, Inc., 1969), pp. 102-103.

[20] Bautista, p. 4., citing Ginsburg and Opper, Piaget's Theory of Intellectual Development, n. 11.

m. Class Inclusionl Class inclusion is the "ability to manipulate part-whole relationships within a set of categories. It is possible to put together two classes to form a larger one or take away a part from the whole."[22]

n. Combinatorial Operations. Combinatorial operations are the linking of all variables with each other in all possible ways. ". . . the adolescent can consider all these possibilities and combine them in such a way as to enable him to decide which of a number of potential explanations, in fact, explains the situation."[23]

o. Separation of Variables. Separation of variables is an operation that allows recognition of the different factors that enter into a complex situation.[24]

p. Reciprocal Implication. Reciprocal implication is a "type of reversibility in which the effect of a force or action is compensated by another force or action."[25] The implications are postulated and do not result merely from empirical data.

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[21] Bautista, p. 4, citing Jean Piaget, Psychology of Intelligence, n. 8.

[22] Bautista, p. 4, citing Inhelder and Piaget, The Growth of Logical Thinking, n. 10.

[23] Bautista, p. 5.

[24] Inhelder and Piaget, The Growth of Logical Thinking, p. 61.

q. Exclusion. "Exclusion is an operation that can be carried out after separation of variables. It involves the ability to recognize that, of the existent variables, only one actually plays a causal role."[26]

r. Probability. In establishing probabilities, the student establishes the ratio between those instances which actually occur and the total possible instances of the event.

s. Proportional Reasoning. "Proportional reasoning is the ability to combine two ratios into an equivalence. It is linked to the double reversibility of reciprocals and inversions."[27]

t. Propositional Thinking. Propositional thinking involves the formulation of hypotheses and the

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[25] Johnson, p. 4, citing Richard M. Gorman, Discovering Piaget: A Guide for Teachers (Columbus, Ohio: Charles E. Merrill Co., 1972), n. 17.

[26] Johnson, p. 4, citing Bautista, n. 16.

[27] Bautista, pp. 5-6, citing Inhelder and Piaget, The Growth of Logical Thinking, n. 16.

> development of deductions which, but not necessarily, culminate in experimental verification."[28]

Although Piagetian theory provides a way of analyzing and classifying concepts, there was a need to define the level and type of concept to be identified and then classified. The following definitions are proposed by the investigator.

Major Concepts in Physics Textbooks. The chapter heading in a given textbook will be an indication of the major concept developed in the chapter. If the heading is not stated in conceptual terms, then the investigator will infer from the chapter that concept which has greatest generality. In some chapters, the major concept will be defined as that concept which is crucial to the development of additional concepts in that chapter.

Concepts related to the development of historical, philosophical, sociological, technological, and epistemological ideas of physics will be omitted. Similarly, any concepts concerning laboratory techniques, procedures, and facts will not be considered. Concepts which are principally mathematical, e.g., orders of magnitude, significant figures, will be omitted.

Minor Formal Concepts in Physics Textbooks. Minor formal concepts are those formal concepts which are subsumed within the major concept. Hence minor concepts are more specific and limited than major concepts. Whenever a concrete concept was identified in a textbook it was accompanied by minor formal concepts. The concrete concepts and minor formal concepts combined to form the more general major concept.

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[28] Bautista, p. 5, citing Inhelder and Piaget, The Growth of Logical Thinking, n. 13.

Since this study dealt with 949 students in the State of Oklahoma, the populations and samples were defined as indicated below. During the study, thirteen schools in the State of Oklahoma were visited between January and May, 1976. Tenth, eleventh and twelfth grade students were administered four Piagetian tasks by six examiners.

There were three populations for this study. The total student population or total population represented all tenth, eleventh and twelfth grade students at the thirteen schools. Amongst this population there was a physics student population defined as all students who were studying or who had studied physics up to the time of visiting each school. The potential physics student population contained all students who had never taken a physics course up to the time of the school visit. Therefore, the physics student and potential physics student populations formed the total student population.

Three samples were formed from these populations. The total student sample or total sample consisted of 949 tenth, eleventh, and twelfth grade students randomly selected by the principal at each of the thirteen schools for participation in this study. Within this sample, there was a physics student sample which contained all students who were studying or who had studied physics up to the time of being interviewed. A potential physics student sample represented all students who had never taken a physics course up to the time of being interviewed. Therefore, the physics student and potential physics student samples gave the total student sample.

Premises of the Study

The premise accepted from Piagetian theory was that the tasks can be used to measure formal and concrete operational levels of intellectual development. Research conclusions obtained by Lawson were accepted as premises. These are that formal operational thinking students understand both concrete and formal operational concepts, whereas concrete operational students understand concrete but not formal operational concepts.[29] Furthermore, the conclusion from the research of Bautista that a concept classification system based on the Piagetian model can be used to classify science concepts was accepted as a premise.[30]

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[29] Lawson, pp. 87-93.

[30] Bautista, p. 71.

Need for the Study

The need for this study arose from the recommendations made by Bautista and Lawson, and implied by Johnson. The significant parts of those recommendations follow.

1. Bautista suggested the classification of major concepts in physics and an examination of the incompatibility with the intellectual level of students studying that discipline.[31]
2. Lawson recommended a careful re-evaluation of the major content of the science courses developed during the 1960's in an attempt to better fit that content to the level of the learner. He also suggested that if science courses were constructed with the learner, as well as the structure of the discipline, in mind, then courses such as chemistry and physics might no longer be the choice of only the educationally elite, but could become viable and meaningful disciplines for the majority of students.[32]
3. Johnson reported that the operational level of the biology students was incompatible with the majority of the biology concepts presented to

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[31] Ibid., p. 73.

[32] Lawson, p. 94.

these students. ". . . it seems that much time is wasted in attempting to teach formal biology concepts."[33]

This study is designed to determine the compatibility of physics concepts presented in textbooks with the intellectual level of two groups of students, those enrolled in physics and those eligible for enrollment in physics.

Limitations

The limitations of this study are related to the particular textbooks from which the concepts were selected and the nature of the sample.

To obtain a representative sample of concepts taught in physics courses in the State of Oklahoma, it was decided to select concepts from the textbooks recommended on the State of Oklahoma approved list. The selected texts were: P.S.S.C. Physics;[34] Investigations in Physics;[35] Physics;[36] The World of Physics;[37] and Modern Physics.[38] The text

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[33] Johnson, p. 71.

[34] Uri Haber-Schaim, et al., P.S.S.C. Physics (Boston: D.C. Heath, 1965).

[35] John W. Renner and Harry B. Packard, Investigations in Physics (Chicago: Lyons and Carnahan, 1974).

[36] Irwin Genzer and Philip Youngner, Physics: Teacher's Edition (New Jersey: Silver Burdett, 1973).

[37] Robert Hulsizer and David Lazarus, The World of Physics (Menlo Park, California: Addison and Wesley, 1972).

[38] John Williams, et al., Modern Physics: Teacher's Edition (New York: Holt, Rinehart, Winston, 1972).

Project Physics[39] was included in the study because it was produced by a recent, major physics-curriculum development project. This text was used at one of the schools in this study.

One limitation is related to the sample. The sample may not be random and, therefore, not necessarily representative of the physics students or potential physics student population.

Review of the Literature

Educational and psychological literature contains considerable research into Piagetian theory and comparative studies of science curricula. However, few studies deal with analyzing science concepts in terms of the mental operations required for understanding and relating these concepts to the intellectual levels of science students.

In a study with 46 biology, 48 chemistry, and 33 physics students, Lawson found that concrete operational students understood concrete concepts, but did not understand formal concepts. He also found that "formal subjects did significantly better than concrete subjects on both concrete and formal examination questions."[40] The results indicated that a substantial proportion of science content was inappropriate for the intellectual level of development of the students.

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[39] Gerald Holton; Fletcher Watson; and F. James Rutherford, Project Physics: Text (New York: Holt, Rinehart, Winston, 1972).

[40] Lawson, p. 92.

Bautista developed a concept classification scheme based on the Piagetian model. In her study of physics and chemistry concepts taught to eleventh and twelfth grade students, the majority of concepts were classified as formal. Data on the greater success of formal students than concrete students on formal questions supported Lawson's conclusions.[41]

Johnson found that of the biology concepts classified from the textbook, 73.7 percent were formal operational concepts. Of the 51 students enrolled in biology, 80.4 percent were either concrete or post-concrete, 19.6 percent were beginning formal or formal operational. "These data clearly indicate that the operational level of the biology students and the majority of the biology concepts presented are not compatible."[42]

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[41] Bautista, p. 61

[42] Johnson, p. 71.

CHAPTER II

PROCEDURES OF THE STUDY

The major aim of this study was to examine the compatibility between physics concepts and the intellectual levels of students.

Hypotheses

The following hypotheses were proposed:

1. In the total student population, the majority of physics students are at the formal operational level of intellectual development.
2. The potential physics student population contains a smaller proportion of students at the formal operational level of intellectual development than the physics student population.
3. A high proportion of the major concepts presented in high school physics textbooks are formal rather than concrete operational concepts.

Selection of Subjects

Subjects for this study were selected from thirteen schools in the State of Oklahoma. These high schools were in

Blanchard, Edmond, Grove, Lexington, Mustang, Noble, Oklahoma City (Northwest Classen, Casady and Millwood), Purcell, Tecumseh, Wetumka and Yukon. Tenth, eleventh, and twelfth grade students were randomly selected by the principal of each school for participation in this study. Grade, sex, birthdate, and whether the student was at present studying or had studied physics were recorded.

Instruments Used in the Research

Piagetian Tasks

Four tasks adapted from Piaget and Inhelder[1] and Piaget, Inhelder and Szeminska[2] were administered to each subject to determine intellectual level of development. Six examiners administered the tasks to the sample. The tasks used were:

1. Conservation of volume,
2. Separation of variables,
3. Equilibrium in the balance, and
4. Combinations of colorless chemical liquids.

Subjects were scored separately on each task. The responses were classified as follows:

IIA--early concrete

IIB--late concrete

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[1] Inhelder and Piaget, The Growth of Logical Thinking.

[2] Jean Piaget; Bärbel Inhelder; and Alina Szeminska, The Child's Conception of Geometry (New York: Harper and Row, 1960).

IIIA--early formal

IIIB--late formal

Description of the Piagetian Tasks[3]

Conservation of Volume

The subject was shown two identical test tubes partially filled with water. Time was allowed for the student to adjust the water levels until he believed them to be equal. Two cylinders, made of different metals, but with the same size and shape, were shown to the student. The properties of identical size and shape were pointed out to the student. These two cylinders were handed to the student, who then identified the weight as one property in which the cylinders were obviously different. The examiner then lowered the lighter cylinder into one of the test tubes. The student was asked to predict the water level when the heavier cylinder was lowered into the second test tube.

Successful prediction of the water level and correct explanation was classified as IIIA. Incorrect prediction of the water level, but correct explanation after the student had seen the event was classified as IIB. An incorrect prediction and explanation was classified as IIA. This task does not include a IIIB classification.

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[3] John W. Renner, et al., "Interviewing Protocols for Tasks to Determine Levels of Thought." (Unpublished manuscript, Cognitive Analysis Project, The University of Oklahoma, 1976).

Separation of Variables

The subject was shown the apparatus which consisted of six flexible metal rods of varying thickness, material, and length. A set of weights to hang on the ends of the rods was given to the student. After the equipment was demonstrated to the student, time was allowed for the student to explore the apparatus. The four variables associated with the bending of the rods were pointed out to the student. The student was then asked to demonstrate experiments which would show the effect of each one of the four variables on how much the rods would bend.

Successful demonstration and explanation of all four variables with appropriate controls was classified as IIIB. Successful demonstration and explanation of one, two, or three variables with appropriate controls was classified as IIIA. A subject who confounded all the variables but demonstrated logical multiplication, such as:

(thicker) x (longer) = (thinner) x (shorter)

was classified as IIB. Simple classification into thicker, thinner, longer, shorter, steel, brass, aluminum, was rated as IIA.

Equilibrium in the Balance

The subject was shown the apparatus which consisted of a balance bar with seventeen evenly spaced hooks on each side of the fulcrum. The examiner explained to the student that weights would be hung on one side of the bar and the student was required to hang given weights on the other side to make the bar balance. A series of activities was then carried out with the student. The quantities dealt with in these activities are given in Table 2-1.

TABLE 2-1

QUANTITIES USED IN EQUILIBRIUM IN THE BALANCE

	Examiner		Student
Activity No.	Weight Selected (g)	Number Of Hooks From Which The Weight Was Hung	Weight Given To Student (g)
1	100	6	100
2	100	6	50 + 50
3	100	6	50
4	120	3	40
5	70	10	100
6	60	6	40

Whilst the student was determining the proper location for the given weight, the examiner held the balance bar. Before releasing the bar, the student was asked to explain why he had selected that particular hook.

If the subject was not successful with anything beyond activity two, then the subject was classified as IIA. The IIB subject was successful with the 2:1 proportion of activity three.[4] A correct explanation in terms of the proportion concept had to be given to be classified as IIB. The successful completion of activity four, including an explanation involving the proportion concept, was classified as IIIA. Successful completion of activity five, including an explanation using the proportion concept, was classified as IIIB. If the examiner was unsure of his judgment after using activity five, activity six was carried out. The same criteria for IIIB classification would apply in both activities.

Combinations of Colorless Chemical Liquids

The subject was shown five bottles labeled "1," "2," "3," "4," and "g" and a rack of small test tubes.

The contents of the bottles were as follows:

Bottle 1 - Dilute sulphuric acid

Bottle 2 - Distilled water

Bottle 3 - Dilute hydrogen peroxide

Bottle 4 - Sodium thiosulfate

Bottle g - Potassium iodide

Without the student's knowledge, clear liquids from these bottles had been placed in two test tubes. One test tube contained a mixture from bottles one and three. The other test tube contained solution from bottle two.

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[4] Piaget and Inhelder infer (Growth of Logical Thinking, Chapter II) that the successful completion of the 2:1 ratio task is a characteristic of the IIIA category. W. Wollman and R. Karplus ("Intellectual Development Beyond Elementary School V: Using Ratio in Differing Tasks," School Science and Mathematics, Vol. LXXIV, No. 7, Nov. 1974, pp. 593-611) have shown the 2:1 ratio concept to be attainable at the IIB level.

The clear liquid in each test tube was pointed out to the student. Whilst the student observed, the examiner added liquid from bottle "g" to each of these clear liquids. The yellow color change which occurred in one solution, but not the other, was noted by the student. Then the student was asked to do as many experiments as he needed in order to reproduce the yellow color change in as many different ways as he could.

A IIA subject simply combined a single liquid with "g" or all four with "g" without any other combinations. The IIB subject carried out some n x n combinations with "g" or n x n x n combinations with "g." The system demonstrated by this category of response was empirical and the subject attributed the color change to one particular liquid. The introduction of a systematic method in the use of n x n combinations and an understanding that the color resulted from a combination rather than coming from one of the liquids was classified as a IIIA response. If the response indicated that the combinations and proofs were organized in a more systematic fashion, with the experiment organized from the start with the intention of finding proof, then the response was classified as IIIB. Responses in this category included determination and proof of the roles of water and sodium thiosulfate in the combinations.

Concept Classifications

The major concepts in the textbook chapters were classified into concrete or formal operational concepts using three different types of analysis. These three types of analysis were:

a. Using the definitions of concrete and formal operational concepts developed by Lawson. Concrete concepts were developed from first-hand experiences with objects or events, whilst formal concepts required the use of hypothetico-deductive logic.

b. Relating the concept, if possible, to particular mental operations indicated by Inhelder and Piaget as appearing at the formal operational stage in a variety of situations.[5] These operations[6] were

- --proportions
- --coordination of two systems of reference and the relativity of motion or acceleration
- --mechanical equilibrium

---

[5] Inhelder and Piaget refer to these mental operations as operational schemata or operatory schemes or concepts. Their major characteristic is that they are only available to the adolescent who is at the formal operational stage of intellectual development. To avoid confusion with any previous use of the term concept, the investigator will refer to them as operations or mental operations.

[6] Inhelder and Piaget, The Growth of Logical Thinking, pp. 308-329.

--probability

--forms of conservation which go beyond direct empirical verification

b. Following Bautista's concept classification system.[7] The concept was defined using the following criteria related to mental operations:

--classification

--1:1 correspondence

--seriation

--class inclusion

concrete operational concepts

--combinatorial operations

--proportional reasoning

--separation of variables

--reciprocal implication

--exclusion

--probability

formal operational concepts

The concept classification scheme developed by Bautista and used by Johnson was modified for this investigation. Propositional thinking as a separate mental operation was omitted and the operations of classification and probability were added.

Concrete concepts can be developed from first-hand experience simply by arranging objects in classes according to certain criteria. This learning requires the mental operation of classification. A different concept, however, can require the mental operation of class inclusion, in which relationships in a class are subsumed within another more general class or category. Therefore, the investigator regarded class inclusion operations as dependent upon but extending classification operations. Hence, these two mental operations were separated in the classification system.

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[7] Bautista, pp. 26-31.

Some physics concepts such as chance, randomness, uncertainty and indeterminacy involve the mental operations of probability. This operation was added to the classification scheme.

The mental operation specified by Bautista, propositional thinking, was omitted. If formal thinking is essentially hypothetico-deductive, then deductions will be made from hypotheses which have been formulated from propositions.[8] Therefore, the investigator viewed propositional thinking as synonymous with formal thinking, not one of several separate, yet coordinated mental operations.

Treatment of Data

Piagetian Tasks

The inter-rater reliability on the administration of the four Piagetian tasks was first analyzed by determining t-scores for each examiner. The mean scores for performance on the three tasks were calculated by allocating a IIA thought type a score of 1; IIB a score of 2; IIIA a score of 3; and IIIB a score of 4. Statistical data on inter-rater reliability are presented in Chapter III.

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[8] Inhelder and Piaget, The Growth of Logical Thinking, p. 251.

Three different methods of analyzing the data from the samples will be described. The total student sample was subdivided into two groups--physics student and potential physics student samples. In each student sample categories of responses to three Piagetian tasks were grouped according to criteria established for the method of analysis. The percentages of responses in particular groups allowed a comparison to be made of the different student samples.

The investigator used data from performance on only three Piagetian tasks for each analysis. When rating a student's performance on the tasks, the maximum score which could be achieved on the conservation of volume task was IIIA, whereas IIIB responses were possible for the other three tasks: separation of variables, equilibrium in the balance, combination of colorless chemical liquids. Therefore, only those tasks which permitted a IIIB rating were used. The investigator considers this an equitable method of comparing student samples.

Analysis I

The percentage of formal thought in the sample was computed by dividing the number of times formal thought was demonstrated by the total number of opportunities provided for formal thought. This percentage was calculated for the three samples.

With the three tasks which permitted a IIIB rating, each student had the opportunity to exhibit IIIB thought three times during an interview. Similarly, each of the other thought types, IIIA, IIB, IIA, could have been exhibited three times during an interview. Combinations of varying amounts of these thought-types could also have been exhibited.

The total number of times each of the four categories of response was exhibited was determined for each sample. Responses IIA and IIB were classified as indicating concrete thought, IIIA and IIIB as formal thought.

Analysis III

Each student's responses on the three Piagetian tasks were placed into one of the following seven groups:

a. all IIA responses--Concrete IIA

b. some IIA and some IIB responses--Transitional Concrete

c. all IIB responses--Concrete IIB

d. some IIA and/or IIB responses and some IIIA and/or IIIB responses--Post-Concrete

e. all IIIA responses--Formal IIIA

f. some IIIA and some IIIB responses--Transitional Formal

g. all IIIB responses--Formal IIIB

Analyses I and II were selected to avoid horizontal décalage which could occur in the performance on the three

Piagetian tasks. In these analyses the individual student was not the unit of measurement.

Analysis III

Patterns of responses in the physics sample were identified. Data from the potential physics and total student samples were not analyzed because the samples were too large. Each pattern was grouped according to the following criteria:

--Formal if the pattern contained only formal responses

--Transitional Formal if the pattern contained 2/3 formal and 1/3 concrete responses

--Post-Concrete if 2/3 concrete and 1/3 formal responses were found in the pattern

--Concrete if only concrete responses were obtained.

Concept Classification

A number of the textbooks used in this study had accompanying laboratory manuals. The investigator decided only to analyze the concepts as presented in the text and not consider how the concepts might have been developed if experiments had been used to accompany the text.

Some teacher's editions of the textbooks listed the main ideas in particular chapters. However, the investigator analyzed how the concepts in the text were presented to the student.

Frequently in the textbooks a topic would be introduced using or defining a major concept which was formal.

Examples or applications would follow this formal concept. According to both Lawson's and Bautista's definitions, a concrete operational concept develops from first-hand experiences and the use of mental operations such as classification and one-to-one correspondence. Therefore, concrete concepts are not developed by analogies or by applying formal concepts to concrete objects or experiences.

In some texts concepts were developed by leading the student through the historical development of physics concepts. However, this investigation was not concerned with the format in which concepts were developed. Therefore, the progressive developments of concepts throughout history were not classified by the investigator.

Just to identify and classify the major concepts presented in each chapter of a textbook does not necessarily provide a comprehensive analysis of the concepts presented in the texts. Therefore, in addition to classifying major concepts, any concrete concepts presented in the chapters were identified, using the definition proposed by Lawson, and related to the major concept through minor formal concepts.

CHAPTER III

PRESENTATION AND INTERPRETATION OF DATA

Data collected during this investigation were for the purpose of determining the compatibility between the intellectual level of development of physics and potential physics students, and the operational levels of physics concepts as presented in physics textbooks. The data are presented in four sections.

Section A presents data dealing with the levels of intellectual development, determined by Piagetian tasks, of the samples. Inter-rater reliability between each of the six examiners who conducted the Piagetian task interviews will also be discussed.

An analysis of the physics concepts will be presented in Section B. Major concepts in each textbook chapter were analyzed. Additional data related to concrete operational concepts identified throughout the texts to the major concepts will be provided.

These first two sections provide the necessary data to determine the degree of compatibility between the physics and potential physics samples and the operational levels of physics concepts. Section C, therefore, will be an evaluation of the hypotheses of this study.

Because this investigation provides information on one aspect of the characteristics of physics students, data obtained on other characteristics by other researchers will be discussed in Section D. Investigations dealing with the causes of declining enrollments in high school physics courses will also be discussed.

Section A

From January through May, 1976, six examiners interviewed 949 tenth, eleventh and twelfth grade high school students from thirteen schools in the State of Oklahoma with four Piagetian tasks. These tasks were conservation of volume, separation of variables, equilibrium in the balance, and combinations of colorless chemical liquids.

Throughout this period various procedures were instigated to achieve and determine inter-rater reliability among the six examiners. Initially all six examiners were trained by the one person and protocols were established for each of the four tasks. Approximately 200 high school students were interviewed by the examiners before finalizing the protocols and beginning to collect the data from the samples. Each protocol was meant to reflect the criteria established by Inhelder, Piaget and

Szeminska,[1,2] except that for all tasks any student in the I or IIA categories was rated as IIA. One additional exception to the criteria established by Inhelder and Piaget for the equilibrium in the balance task has already been noted in Chapter II.

The format required for administering Piagetian tasks precludes the same student from being interviewed on the same task by all six examiners. Hence it was impossible to obtain a statistical analysis of the examiners' ratings which would establish the sufficient condition required for inter-rater reliability. However, the investigator believed that the nature of the training sessions for the examiners and the monitoring procedures used throughout the interviewing period established the sufficient condition for inter-rater reliability.

To establish the necessary condition for inter-rater reliability, it should be demonstrated that the ratings of the six examiners differ only by chance. The mean scores obtained by the six examiners on each of the four tasks were calculated and are presented in Table 3-1.

These scores have a mean of 2.38 and a standard deviation of 0.07. It would appear that there were no significant differences between the six examiners. Any inferential

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[1] Inhelder and Piaget, The Growth of Logical Thinking.

[2] Piaget, Inhelder and Szeminska, The Child's Conception of Geometry.

TABLE 3-1

MEAN SCORES OBTAINED BY SIX EXAMINERS

Examiner	N	Conservation of Volume	Separation of Variables	Equilibrium in Balance	Colorless Liquids	Total
1	253	2.39	2.57	2.08	2.42	2.36
2	155	2.37	2.90	2.28	2.30	2.46
3	174	2.26	2.55	2.00	2.43	2.31
4	165	2.44	2.67	2.35	2.44	2.47
5	172	2.37	2.39	2.09	2.34	2.30
6	30	2.37	2.30	2.33	2.50	2.38
Total		2.37	2.60	2.15	2.39	2.38

statistical analysis would involve the large sample sizes of five examiners. Such analysis would require techniques which would be so powerful that distortion of insignificant variations between the examiners could result. Therefore, inferential statistics could at best just provide an indication of the necessary condition of inter-rater reliability. Such analysis was carried out by calculating a t-score for each examiner. The null hypothesis tested was that the ratings of the six examiners differ only by chance. The data are presented in Table 3-2.

TABLE 3-2

t-SCORES OBTAINED BY SIX EXAMINERS

Examiner	t-Scores
1	$t(252) = -0.256, p > 0.01$
2	$t(154) = 0.802, p > 0.01$
3	$t(173) = -0.744, p > 0.01$
4	$t(164) = 0.931, p > 0.01$
5	$t(171) = -0.845, p > 0.01$
6	$t(29) = 0.000, p > 0.01$

The null hypothesis was accepted at the 0.01 level of confidence. Therefore, the necessary condition for interrater reliability was indicated.

Of the 949 high school students interviewed, 54 students had studied or were studying physics. Therefore, there were 895 potential physics students in the total student sample. Raw data obtained from the performance of these 54 physics students on the four Piagetian tasks is given in Table 3-3. The grade column indicates the grade in which the student was enrolled at the time of the interviewing, not the grade during which the student studied physics. The student number is a means of identifying each pupil and has no other significance.

TABLE 3-3

RAW DATA FOR THE PHYSICS STUDENTS

Student Number	Sex	Grade	Task 1	2	3	4	Totals of Columns 2, 3, 4 IIA	IIB	IIIA	IIIB
1	M	11	IIIA	IIIA	IIIA	IIB	0	1	2	0
2	M	12	IIIA	IIIB	IIIA	IIIB	0	0	1	2
3	M	12	IIIA	IIIB	IIIB	IIIB	0	0	0	3
4	F	12	IIIA	IIIB	IIIA	IIIA	0	0	2	1
5	M	12	IIIA	IIIB	IIIB	IIIA	0	0	1	2
6	M	12	IIIA	IIIB	IIIB	IIIB	0	0	0	3
7	F	11	IIIA	IIIB	IIIA	IIB	0	1	1	1
8	F	11	IIB	IIIA	IIB	IIB	0	2	1	0
9	M	12	IIIA	IIIB	IIIB	IIIA	0	0	1	2
10	M	12	IIB	IIIB	IIIA	IIIB	0	0	1	2
11	F	12	IIIA	IIIB	IIIA	IIIA	0	0	2	1
12	M	12	IIIA	IIIA	IIB	IIB	0	2	1	0
13	M	12	IIIA	IIIB	IIIB	IIB	0	1	0	2
14	M	12	IIIA	IIIB	IIIB	IIIA	0	0	1	2
15	M	12	IIIA	IIIB	IIIA	IIB	0	1	1	1
16	M	12	IIIA	IIIA	IIIA	IIIA	0	0	3	0
17	M	12	IIIA	IIIA	IIB	IIIA	0	1	2	0
18	M	12	IIIA	IIIA	IIB	IIB	0	2	1	0
19	M	12	IIIA	IIIB	IIIB	IIIA	0	0	1	2
20	M	12	IIIA	IIIA	IIIA	IIB	0	1	2	0
21	M	12	IIIA	IIIB	IIIA	IIB	0	1	1	1

TABLE 3-2--Continued

Student Number	Sex	Grade	Task 1	Task 2	Task 3	Task 4	Totals of Columns 2, 3, 4 IIA	IIB	IIIA	IIIB
22	M	12	IIIA	IIIA	IIIB	IIIA	0	0	2	1
23	M	12	IIIA	IIIA	IIIA	IIIB	0	0	2	1
24	M	12	IIIA	IIIA	IIIB	IIIA	0	0	2	1
25	F	12	IIIA	IIIA	IIA	IIB	1	1	1	0
26	M	12	IIIA	IIIB	IIIA	IIIA	0	0	2	1
27	M	12	IIIA	IIIB	IIIB	IIIB	0	0	0	3
28	M	12	IIIA	IIA	IIIA	IIIA	1	0	2	0
29	M	12	IIB	IIIA	IIIA	IIIA	0	0	3	0
30	F	11	IIIA	IIA	IIA	IIB	2	1	0	0
31	M	11	IIIA	IIB	IIIB	IIIB	0	1	0	2
32	M	12	IIB	IIB	IIIA	IIB	0	2	1	0
33	M	12	IIIA	IIIB	IIIB	IIIA	0	0	1	2
34	F	12	IIA	IIB	IIB	IIIA	0	2	1	0
35	F	12	IIIA	IIIA	IIIA	IIIA	0	0	3	0
36	F	12	IIB	IIA	IIA	IIB	2	1	0	0
37	M	12	IIB	IIIB	IIB	IIIB	0	1	0	2
38	F	11	IIB	IIB	IIB	IIB	0	3	0	0
39	M	12	IIIA	IIIB	IIIB	IIIB	0	0	0	3
40	M	12	IIB	IIIA	IIB	IIB	0	2	1	0
41	F	12	IIIA	IIIB	IIIB	IIIB	0	0	0	3
42	M	12	IIIA	IIIA	IIB	IIIA	0	1	2	0
43	M	12	IIIA	IIIB	IIIB	IIIB	0	0	0	3
44	F	12	IIB	IIIA	IIA	IIIB	1	0	1	1

TABLE 3-2--Continued

Student Number	Sex	Grade	Task 1	Task 2	Task 3	Task 4	Totals of Columns 2, 3, 4 IIA	IIB	IIIA	IIIB
45	M	12	IIIA	IIIB	IIIA	IIIB	0	0	1	2
46	M	11	IIIA	IIIB	IIIB	IIIB	0	0	0	3
47	F	12	IIIA	IIIA	IIIA	IIB	0	1	2	0
48	M	12	IIB	IIIA	IIIA	IIB	0	1	2	0
49	M	11	IIIA	IIB	IIA	IIB	1	2	0	0
50	M	12	IIIA	IIIB	IIIA	IIIA	0	0	2	1
51	M	12	IIIA	IIIA	IIIB	IIIA	0	0	2	1
52	M	12	IIIA	IIIA	IIIA	IIB	0	1	2	0
53	M	12	IIIA	IIIB	IIIA	IIB	0	1	1	1
54	M	12	IIIA	IIIB	IIIB	IIIA	0	0	1	2

Task 1 = Conservation of volume

Task 2 = Separation of variables

Task 3 = Equilibrium in the balance

Task 4 = Combination of colorless chemical liquids

Analysis I

This analysis allowed comparison of different student samples by determining the percent of times formal and concrete thought were exhibited. The distribution of thought type found in the three samples is presented in Table 3-4. These results are shown graphically in Figure 3-1.

The data indicate that the physics sample exhibited formal thought 74.1 percent of the time in which formal

TABLE 3-4

DISTRIBUTION OF TYPES OF THOUGHT IN THE THREE SAMPLES

Thought Category	Thought Type	Number of Times Thought Type Found		
		Total	Potential Physics	Physics
Concrete	IIA	424	416	8
	IIB	1222	1188	34
Formal	IIIA	898	836	62
	IIIB	303	245	58

		Percent of the Total of Thought Types Found					
		Total	Potential Physics	Physics	Total	Potential Physics	Physics
Concrete	IIA	14.9	15.5	4.9			
	IIB	42.9	44.3	21.0	57.8	59.8	25.9
Formal	IIIA	31.5	31.1	38.3			
	IIIB	10.7	9.1	35.8	42.2	40.2	74.1

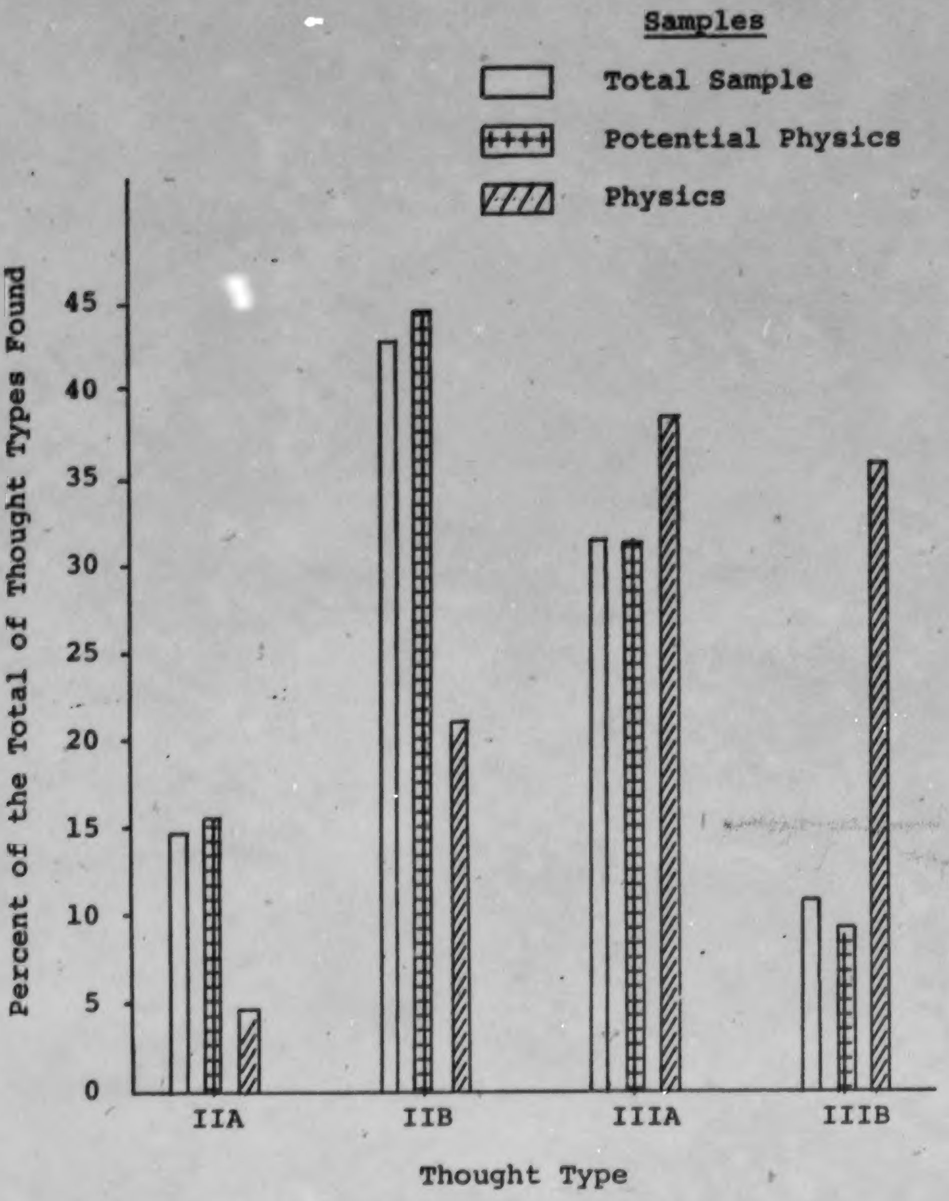
Total Sample N = 949

Potential Physics Sample N = 895

Physics Sample N = 54

Figure 3-1. Distribution of Thought Types in the Three Samples

Analysis I



thought was possible, whereas the potential physics sample exhibited formal thought only 40.2 percent of the time.

For the physics students, IIIA formal thought had the maximum percentage of total thought type found. The second highest percentage for these students occurred in the IIIB formal thought category. However, for the potential physics student sample the maximum percentage of total thought type occurred in the IIB concrete category. For this sample, the second highest percentage of thought type occurred in the IIIA formal thought category.

Analysis II

With this analysis, each student's responses on three tasks were placed into one of seven groups.

Table 3-5 presents the operational levels of the three samples. A graphical representation of the data is given in Figure 3-2.

The data indicate that 50 percent of the physics sample gave responses involving IIIA and/or IIIB categories, whereas only 16.9 percent of the potential physics sample gave these groups of responses.

Consider responses which involve only IIA and/or IIB categories. These responses were given by 35.7 percent of the potential physics sample, yet only 7.4 percent of the physics sample gave these types of responses. Furthermore, no physics student gave a concrete IIA response.

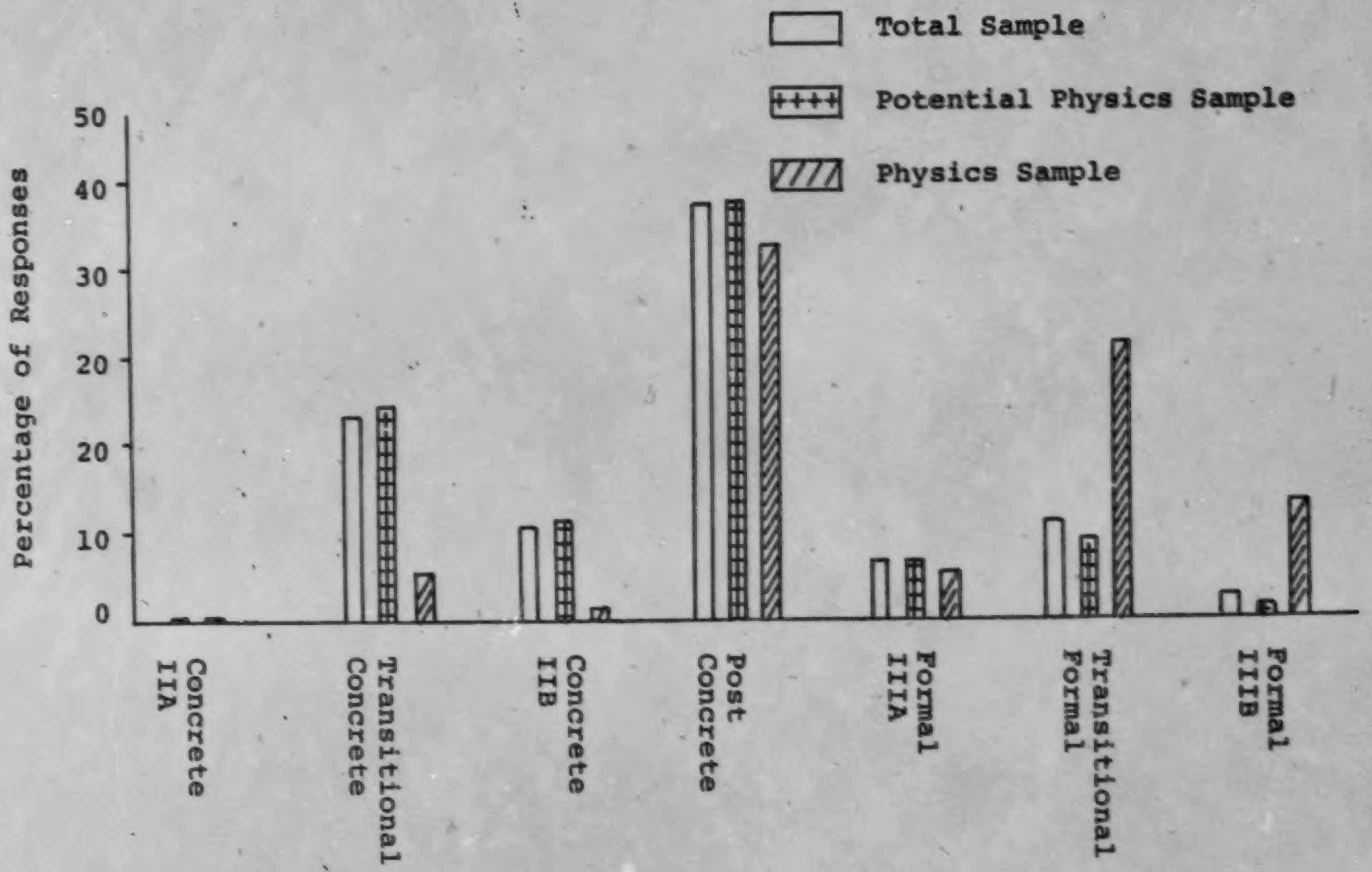
TABLE 3-5

RAW DATA ON THE THREE SAMPLES

	N	Concrete IIA	Transitional Concrete	Concrete IIB	Post Concrete	Formal IIIA	Transitional Formal	Formal IIIB
Total								
Number	949	7	220	97	447	59	98	21
Percent		0.8	23.2	10.2	47.1	6.2	10.3	2.2
Potential Physics								
Number	895	7	217	96	424	56	81	14
Percent		0.8	24.2	10.7	47.4	6.2	9.1	1.6
Physics								
Number	54	0	3	1	23	3	17	7
Percent		0	5.5	1.9	42.6	5.5	31.5	13.0

Figure 3-2. Percentages of Responses in the Three Samples

Analysis II



Although the highest percentage of responses for both physics and potential physics students occurred in Post Concrete, consider the groups where the second highest percentage occurred--Transitional Formal for the physics population (31.5 percent) and Transitional Concrete for the potential physics population (24.2 percent).

In the physics sample, 13.0 percent were at the Formal IIIB level, yet only 1.6 percent of the potential physics sample reached this level.

Analysis III

The performance on the three tasks was analyzed for each student to identify patterns of responses in the physics sample. Table 3-6 summarizes the different patterns of responses with the frequency of the appearance of each pattern. The pattern number has no significance other than to designate a particular pattern. These patterns can be grouped as follows:

Patterns 1-4: Formal
Patterns 5-8: Transitional Formal
Patterns 9-11: Post Concrete
Patterns 12-14: Concrete

Analysis of these four groups of patterns is summarized in Table 3-7. This analysis showed that 50 percent of the physics students were operating at the Formal level. Of the physics students, 77.8 percent, were either Transitional Formal or Formal level.

TABLE 3-6

RESPONSE PATTERNS OF PHYSICS STUDENTS ON THREE PIAGETIAN TASKS

Pattern Number	Pattern				Frequency
1	IIIB IIIB IIIB				7
2	IIIB IIIB	IIIA			9
3	IIIB	IIIA IIIA			8
4		IIIA IIIA IIIA			3
5		IIIA IIIA	IIB		7
6	IIIB IIIB		IIB		3
7		IIIA IIIA		IIA	1
8	IIIB	IIIA	IIB		4
9		IIIA	IIB IIB		6
10		IIIA	IIB	IIA	1
11	IIIB		IIB	IIA	1
12			IIB IIB IIB		1
13			IIB IIB	IIA	1
14			IIB	IIA IIA	2

TABLE 3-7

RESPONSE PATTERNS OF PHYSICS STUDENT SAMPLE

	Number of Students	Percentage
Formal	27	50.0
Transitional Formal	15	27.8
Post Concrete	8	14.8
Concrete	4	7.4

Summary of the Three Methods of Analysis

The different methods for analyzing the data obtained from 949 high school students have been presented. The results of these analyses are given in Table 3-8.

TABLE 3-8

PERCENTAGES OF STUDENTS IN DIFFERENT CATEGORIES OBTAINED FROM DIFFERENT METHODS OF ANALYSIS

Analysis I

Category	Total	Potential Physics	Physics
IIA	14.9	15.5	4.9
IIB	42.9	44.3	21.0
IIIB	31.5	31.1	38.3
IIIB	10.7	9.1	35.8

Analysis II

Category	Total	Potential Physics	Physics
Concrete IIA	0.8	0.8	0
Transitional Concrete	23.2	24.2	5.5
Concrete IIB	10.2	10.7	1.9
Post Concrete	47.1	47.4	42.6
Formal IIIA	6.2	6.2	5.5
Transitional Formal	10.3	9.1	31.5
Formal IIIB	2.2	1.6	13.0

TABLE 3-8--Continued

Analysis III	
Category	Physics
Concrete	7.4
Post Concrete	14.8
Transitional Formal	27.8
Formal	50.0

Data from these three methods of analysis were used to group students into the broad categories of formal and concrete. The concrete group for Analysis Two was defined as incorporating Concrete IIA to Post Concrete and the formal group as involving Formal IIIA to Formal IIIB. The results of this broad categorization into formal and concrete are given in Table 3-9.

There was remarkable similarity between analyses One and Three for the physics sample. Both analyses One and Two show that the physics sample has a higher proportion of students at the formal operational level of intellectual development than the potential physics sample.

In analyses One and Three, the majority of physics students were at the formal operational level. The criteria for the formal level in Analysis Two were particularly rigorous. A student may have up to two-thirds of his responses in the IIIB category yet a IIB response would place

TABLE 3-9

BROAD CATEGORIZATION OF THE THREE SAMPLES

	Analysis I			Analysis II			Analysis III
	Total	Potential Physics	Physics	Total	Potential Physics	Physics	Physics
Concrete	57.8	59.8	25.9	81.3	83.1	50.0	20.2
Formal	42.2	40.2	74.1	18.7	16.9	50.0	77.8

this student into the concrete category. With this distinction between formal and concrete, Analysis Two still showed that 50 percent of the physics students were at the formal level. Consider how this rigorous distinction between formal and concrete categories affected the potential physics group. There were only 16.9 percent of the potential physics group at the formal level, whereas by Analysis One, there were 40.2 percent of these students at the formal level.

Section B

Three methods of analyzing 130 major physics concepts were used to classify the concepts listed in Appendix A. The development and interpretation of this table will now be described. Column L represents the classification using criteria developed by Lawson. The letter F within this column represents a formal concept. The next column, P, represents an analysis of the concepts using criteria derived from Inhelder and Piaget's work. This column represents mental operations which Inhelder and Piaget have indicated as operating at the formal level. All major concepts were analyzed to determine whether these mental operations were required for the student's understanding of the concept. Within this column, labeled P, the particular mental operations are designated as follows:

PR--proportions

FR--coordination of two systems and the relativity of motion or acceleration

ME--mechanical equilibrium

P--probability

CN--forms of conservation which go beyond direct empirical verification

The analysis of concepts using the criteria developed by Bautista also involved identifying mental operations required for the student's understanding of the concept. This analysis has been specified under the column labeled Operations. The particular mental operations specified by Bautista are as follows:

Cl--classification

OC--one-to-one correspondence

S--seriation

CI--class inclusion

CO--combinatorial operations

PR--proportional reasoning

SV--separation of variables

RI--reciprocal implications

E--exclusion

P--probability

Frequently in Appendix A concepts have been abbreviated. A complete explanation of the concepts is given in the Appendix C.

Of the 130 major concepts identified and analyzed in the six textbooks, all major concepts were formal operational according to Lawson's definitions for formal and concrete concepts. The investigator used the mental operations indicated by Inhelder and Piaget as operating at the formal level to determine whether these operations were required for understanding the major concepts. The number of major concepts requiring particular mental operations was determined and the results of this analysis are given in Table 3-10.

TABLE 3-10

ANALYSIS OF MAJOR CONCEPTS USING MENTAL OPERATIONS INDICATED BY INHELDER AND PIAGET

Author of Text	Number of Major Concepts Requiring Particular Mental Operations				
	PR	FR	ME	P	CN
Haber, et al.	29	3	0	4	7
Renner, et al.	19	3	3	4	4
Genzer, et al.	24	3	1	4	6
Holton, et al.	17	2	1	3	4
Hulsizer, et al.	17	2	2	2	4
Williams, et al.	24	0	1	6	8
Total	130	13	8	23	33

PR = proportionality

FR = coordination of two systems and the relativity of motion or acceleration

ME = mechanical equilibrium

P = probability

CN = forms of conservation which go beyond direct empirical verification

The 130 major concepts were further analyzed using the criteria developed by Bautista. The number of major concepts requiring particular mental operations using Bautista's criteria was calculated. Data are given in Table 3-11.

TABLE 3-11

ANALYSIS OF MAJOR CONCEPTS USING MENTAL OPERATIONS IDENTIFIED BY BAUTISTA

Author of Text	Number of Major Concepts Requiring Particular Mental Operations									
	Cl	OC	S	CI	CO	PR	SV	RI	E	P
Haber, et al.	29	29	29	29	29	29	29	29	29	4
Renner, et al.	19	19	19	19	19	19	19	19	19	4
Genzer, et al.	24	24	24	24	24	24	24	24	24	4
Holton, et al.	17	17	17	17	17	17	17	17	17	3
Hulsizer, et al.	17	17	17	17	17	17	17	17	17	2
Williams, et al.	24	24	24	24	24	24	24	24	24	6
Total	130	130	130	130	130	130	130	130	130	23

Cl = classification
OC = one-to-one correspondence
S = seriation
CI = class inclusion
CO = combinatorial operations
PR = proportional reasoning
SV = separation of variables
RI = reciprocal implications
E = exclusion
P = probability

Because five of the textbooks contained concrete concepts, these concepts were identified and are listed in Appendix B. Minor formal concepts, together with the concrete concepts, were used in the textbooks to develop the major concepts. Complete explanations of those concepts which have been abbreviated in Appendix B are given in Appendix C.

The distributions of the physics content of the concrete concepts identified in the textbooks are given in Table 3-12.

Concrete concepts dealing with the properties of light and three-dimensional waves occurred in all five texts. Only three texts, however, dealt with concrete concepts about dynamics, electrostatics and electromagnetism. One text also had concrete concepts related to properties of

TABLE 3-12

DISTRIBUTION OF THE PHYSICS CONTENT OF THE CONCRETE CONCEPTS IN THE TEXTS

Type of Concrete Concept	Author of Text				
	Haber, et al.	Renner, et al.	Genzer, et al.	Holton, et al.	Hulsizer, et al.
Properties of Light	X	X	X	X	X
Properties of Waves					
a. Two-dimensional	X		X	X	X
b. Three-dimensional	X	X	X	X	X
Properties of Gases		X			
Electrostatics	X	X		X	
Current Electricity		X			
Electromagnetism		X		X	X
Gravity		X			
Mechanics		X			
Dynamics	X	X		X	
Energy		X			
Frames of Reference		X			
Total	5	11	3	6	4

gases, current electricity, gravity, mechanics, energy, and frames of reference.

Evidence was found to support the notion that concrete operational concepts can be found in physics textbooks. For example, the concrete concepts in Investigations in Physics, by Renner and Packard, covered almost twice as many different physics content areas as any other text. Concrete concepts in Project Physics, by Holton, et al., covered the second largest number of different physics content areas.

Section C

The major aim of this study was to determine the degree of compatibility between intellectual levels of development of different high school student populations and the operational levels of physics concepts. Data provided in Chapter III, Sections A and B, provide the basis for determining this degree of compatibility. It was expected that the majority of physics students would be at the formal operational level, whilst the potential physics population would contain a smaller proportion of students at the formal level. These hypotheses were tested in the null form. Furthermore, the investigator hypothesized that a high proportion of major concepts would be formal operational concepts.

To determine if the difference in performance on the Piagetian tasks between the three samples was statistically significant the data in Table 3-4 were analyzed. These mean scores were then tested for significant differences using a t-test. The results are given in Table 3-13.

TABLE 3-13

t-TEST OF MEAN DIFFERENCE BETWEEN THE THREE SAMPLES

	N	Mean Score	t-Test
Total Student Sample	949	2.38	
Physics Sample	54	3.10	6.12
Potential Physics Sample	895	2.34	1.36

The t-value for the physics sample exceeds the table value at the 0.01 level of significance, therefore, the hypothesis that no significant differences occur between the physics and total samples must be rejected. The t-value for the potential physics sample does not exceed the table value at the 0.01 level of significance, therefore, the hypothesis that no significant differences occur between the potential physics and total student samples can be accepted.

On the basis of the data presented in Appendix A it can be stated that all 130 major concepts presented in the six textbooks were formal operational. Any concrete concepts which appeared in textbooks were used to develop one of the 130 major formal concepts.

Section D

Different parameters have been investigated by researchers which might indicate the causes of small and declining enrollments in physics.

The following data indicate the eleventh and twelfth grade enrollments in science and physics courses in 1974-1975 in the State of Oklahoma.[3]

Number of students enrolled in Physics I (Eleventh and twelfth grade) = 2,307

Number of students enrolled in Physics II (Twelfth grade) = 104

Number of students enrolled in Science (Eleventh and twelfth grade) = 170,519

Total number of eleventh and twelfth grade students = 640,000

Therefore, 26.6 percent of eleventh and twelfth grade students were enrolled in science courses. However, only 0.4 percent of eleventh and twelfth grade students were enrolled in either Physics I or Physics II. In the eleventh and twelfth grades, 1.4 percent of the science students were enrolled in physics courses.

Some research has identified distinctive characteristics of physics students, other studies have investigated possible causes of declining physics enrollments. A number of these studies will be described in this section.

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[3] Larry McKinney, State Science Consultant, State of Oklahoma, personal correspondence.

In a national sample of 2,419 students, Welch[4] determined I.Q.'s of male and female physics students. These I.Q. scores were at the 84th and 85th percentile, respectively, for all twelfth graders. Similar results were found by Welch[5] in a study of 451 physics students where the I.Q. of these students was at the 82nd percentile, yet the average grade received by these students was in the C+, C- range. In addition, Welch found that the typical male physics student was a bright senior, with strong mathematical and science interests, placed high value on the pursuit of truth, was probably a school leader with strong power and accomplishment drives and planned to attend a four-year college. The typical female physics student had a superior intelligence and greater understanding of science than her peers, strong interests in science and mathematics, and placed high value on the pursuit of truth and power. Welch concluded that physics students were among the academically elite. Dickison[6] found that the majority of teachers rated physics students as predominantly superior or above average compared to non-physics students.

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[4] Wayne W. Welch, "Some Characteristics of High School Physics Students: Circa 1968," Journal of Research in Science Teaching, 1969, 6, No. 3, pp. 242-247.

[5] Wayne W. Welch, "Correlates of Courses Satisfaction in High School Physics," Journal of Research in Science Education, 1969, 6, No. 1, pp. 54-58.

[6] Alexander Dickison, "Physics Teaching in Public High Schools of Montana," Physics Teacher, April 1975, 13, No. 4, pp. 223-266.

A study by Dietrich and Pella[7] concluded that characteristics related to I.Q., post-educational plans and grade point average (G.P.A.) were insufficient to differentiate between physics students in schools with high physics enrollments and physics students in schools with low physics enrollments. Evidence that 75 percent of physics pupils in high physics enrollment schools and 50 percent of the physics pupils in the low physics enrollment schools earned lower grades in physics than in other sciences or other courses in general, helped to support the opinion that physics teachers grade lower than other teachers. Additional evidence supporting this conclusion was reported by Koevering.[8]

Predominant reasons cited by students for enrolling in physics were interest in science and preparation for future education. Students cited reasons for not enrolling in physics as lack of interest, difficulty in mathematics and fear of low grades. Koevering[9] also reports that guidance counselors are directly responsible for low physics enrollments because they require mathematical prerequisites beyond geometry.

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[7] Donald Dietrich and Milton Pella, "Physics Teaching in Wisconsin Schools," School Science and Mathematics, January, 1974, LXXIV, No. 1, pp. 5-12.

[8] Thomas E. Koevering, "The Distinguishing Characteristics of High Schools with High and Low Enrollments in Physics," Journal of Research in Science Teaching, 1971, 8, No. 1, pp. 37-39.

[9] *Ibid.*, p. 39.

Bridgham and Welch[10] suggested an association between the severity of grading and current and future enrollments in physics courses. However, Dietrich[11] reported results which did not appear to support this conclusion.

The study by Welch[12] of 451 physics students found that it was almost impossible to predict the type of student likely to be satisfied in physics before the course started. Results suggested that student satisfaction in physics correlated with success on achievement tests, course grades and general rewarding experiences in the course.

Welch and Walberg[13] investigated the attitudes of teachers in relation to declining physics enrollments. The investigators reported that nothing in the beliefs of physics teachers appeared to be a direct cause of low physics enrollments. Jordan[14] investigated the causes of declining physics enrollments and found that 80 percent of physics students were better achievers than the average non-physics student. Results also indicated that the percentage of seniors taking physics was much lower for students from low socio-economic levels than for seniors from high socio-economic levels. A nearly direct proportional relationship existed between socio-economic level and enrollments in physics courses. Approximately 35-80 percent of all students sampled at each school could have taken the present physics course. Therefore, Jordan concluded that there was a high potential for increasing enrollments in physics.

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[10] Robert G. Bridgham and Wayne W. Welch, "Physics Enrollments and Grading Practices," Journal of Research in Science Teaching, 1969, 6, No. 1, pp. 44-46.

[11] Don Dietrich, "Grading Practices of High School Physics Teachers: A Contributing Factor to Declining Enrollments in Physics?", Science Education, January-March 1973, 57, No. 1, pp. 25-29.

[12] Welch, "Correlates of Course Satisfaction in High School Physics," p. 57.

[13] Wayne W. Welch, and J. J. Walberg, "Are the Attitudes of Teachers Related to Declining Enrollments in Physics?", Science Education, 1967, 51, No. 5, pp. 436-441.

Yale[15] identified three common reasons for low enrollments in the physical sciences. The first of these was insufficient previous preparation by students to be able to do well in the course. Students tend to avoid difficult subjects in order to receive good grades with the least effort. Finally, students were not receiving positive advisement and encouragement to enroll in physical science courses. An additional cause for low enrollments was proposed by Yale, but one which was not mentioned by teachers or administrators. The methods used together with the attitude of the teacher might influence students not to enroll in the course.

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[14] Thomas S. Jordan, "Investigations into the Causes for Decreasing Enrollments in High School Physics," School Science and Mathematics, November 1971, LXXI, No. 8, pp. 697-702.

[15] F. G. Yale, "Why are High School Students Avoiding the Physical Sciences," Science Education, October 1966, 50, No. 4, pp. 325-328.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

This investigation was carried out to find answers to the following questions:

1. What are the intellectual levels of development of physics and potential physics students in the State of Oklahoma?
2. What are the operational levels of physics concepts presented in physics textbooks used in the State of Oklahoma?
3. What, if any, are the relationships between these two questions?

Conclusions

The physics student sample demonstrated a higher level of intellectual development than the potential physics student sample. In one method of analysis the physics student sample had 74.1 percent at the formal level compared with 40.2 percent of the potential physics sample. Another method of analysis indicated that 50.0 percent of the physics sample were formal, whereas 16.9 percent of the potential physics sample were in this category. Two methods of analysis revealed that the majority of physics students were at the formal level--74.1 percent and 77.8 percent. The third method of analysis which used stringent criteria for differentiating between formal and concrete levels indicated half of the physics sample were formal thinkers. Statistically significant differences in performances of the physics and the total student samples led to the conclusion that the physics students were amongst the educationally elite.

All 130 major physics concepts required, for their understanding, formal mental operations. There is a greater degree of compatibility between the physics concepts and the physics students than between the concepts and the potential physics sample. Even so, these formal concepts would only be compatible with 77.8 percent or 50.0 percent or 74.1 percent, depending on the method of analysis, of the formal thinking physics students. Only a few concrete concepts were used in five textbooks to develop major formal concepts. As presented in textbooks, physics concepts are incompatible with the intellectual level of development of the potential physics student sample.

It would appear that there may be causes, other than teachers' grading practices and content difficulty, which affect low and declining enrollments in physics courses. Students may be selecting themselves out of physics courses on the basis of inappropriateness of physics concepts to intellectual development. A substantial portion of physics subject matter is not suitable in terms of the intellectual development of the learner. There is a significant difference between the physics and potential physics samples. Therefore, material presented in textbooks does not invite participation by potential physics students, concrete operational learners, in physics courses. Perhaps both the pedagogy used in physics courses and the material presented in textbooks have accentuated the differences between physics and potential physics students. To increase enrollments in physics courses, concepts in physics textbooks and pedagogy must become available to the concrete operational learner. Karplus has stated that the textbook by Renner, et al., was the only textbook surveyed by one of his graduate students which made any attempt at inquiry.[1] It has already been demonstrated that this text had concrete concepts on almost twice as many different physics topics as any other text surveyed in this investigation. Therefore, it may be that through inquiry, physics concepts can become available to the concrete operational student and hence enrollments in physics courses increased.

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[1] Robert Karplus, Director of Lawrence Hall of Science, University of California, Berkeley, comment made on June 24, 1976, at the American Association of Physics Teachers' Conference, University of Missouri, Rolla.

Recommendations

If it is advisable that physics become a viable educational course for the majority of high school students, then there should be a re-evaluation of the content and teaching procedures used in physics courses. More information is required on the identification and formulation of concrete and formal operational concepts. A study should be made in which both concrete and formal thinkers are taught concrete and formal concepts. Investigations should be made into the teaching procedures most suitable for moving concrete thinkers into the formal level of intellectual development.

Of the three methods used for classifying concepts, Lawson's definitions provide an effective and quick method of identifying formal and concrete operational concepts. Bautista's classification scheme was used on relatively general physics concepts and would be appropriate to more specific concepts. The only advantage of this scheme over Lawson's definition was that it highlighted the requirement of probability as a mental operation for developing understanding of concepts. The analysis of formal concepts which require the mental operations suggested by Inhelder and Piaget provides one way of verifying the classification of a formal concept. A replication of this study into the compatibility of concepts and student populations should be carried out for chemistry, geology, and other courses.

BIBLIOGRAPHY

Books

Genzer, Irwin and Youngner, Philip, Physics: Teacher's Edition, New Jersey: Silver Burdett, 1973.

Ginsberg, Herbert and Opper, Sylvia, Piaget's Theory of Intellectual Development: An Introduction, Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969.

Gorman, Richard M., Discovering Piaget: A Guide for Teachers, Columbus, Ohio: Charles E. Merrill Co., 1972.

Haber-Schaim, Uri, et al., P.S.S.C. Physics, 2nd ed., Boston: D.C. Heath and Co., 1965.

Holton, Gerald; Watson, Fletcher; and Rutherford, F. James, Project Physics: Text, New York: Holt, Rinehart and Winston, 1975.

Hulsizer, Robert and Lazarus, David, The World of Physics, Menlo Park, California: Addison-Wesley Publishing Co., 1972.

Inhelder, Bärbel and Piaget, Jean, The Early Growth of Logic in the Child, New York: W. W. Norton and Co., Inc., 1964.

________. The Growth of Logical Thinking from Childhood to Adolescence, New York: Basic Books, Inc., 1958.

Phillips, John L., Jr., The Origins of Intellect: Piaget's Theory, 2nd ed., San Francisco: W. H. Freeman and Co., 1975.

Piaget, Jean, Genetic Epistemology, New York: W. W. Norton and Co., Inc., 1970.

________. Psychology of Intelligence, Totowa, New Jersey: Littlefield, Adams and Co., 1973.

________. To Understand is to Invent: The Future of Education, New York: Grossman Publishers, 1974.

Piaget, Jean and Inhelder, Bärbel, The Psychology of the Child, New York: Basic Books, Inc., 1969.

Piaget, Jean; Inhelder, Bärbel; and Szeminska, Alina, The Child's Conception of Geometry, New York: Basic Books, Inc., 1970.

Renner, John W.; Bibens, Robert F.; and Shepherd, Gene D., Guiding Learning in the Secondary School, New York: Harper and Row Publishers, 1972.

Renner, John W., and Stafford, Don G., Teaching Science in the Secondary School, New York: Harper and Row Publishers, 1972.

Renner, John W., and Packard, Harry B., Investigations in Physics, Chicago: Lyons and Carnahan, 1974.

Silberman, Charles E., "Crisis in the Classroom," in Curriculum: Quest for Relevance, 2nd ed., edited by Van Til, William, Boston: Houghton Mifflin Co., 1974.

Williams, John E.; Trinklein, Frederick E.; Metcalfe, H. Clark; and Lefler, Ralph W., Modern Physics: Teacher's Edition, New York: Holt, Rinehart and Winston, Inc., 1972.

Periodicals

Bridgham, Robert G., and Welch, Wayne W., "Physics Enrollments and Grading Practices," Journal of Research in Science Teaching, 1969, 6, No. 1.

Dickison, Alexander K., "Physics Teaching in Public High Schools of Montana," Physics Teacher, April 1975, 13, No. 4.

Dietrich, Don, "Grading Practices of High School Physics Teachers: A Contributing Factor to Declining Enrollments in Physics?", Science Education, January-March 1973, 57, No. 1.

Dietrich, Don and Pella, Milton, "Physics Teaching in Wisconsin Schools," School Science and Mathematics, January 1974, LXXIV, No. 1.

Jordan, Thomas E., "Investigations into the Causes for Decreasing Enrollments in High School Physics," *School Science and Mathematics*, November 1971, LXXI, No. 8.

Koevering, Thomas E., "The Distinguishing Characteristics of High Schools with High and Low Enrollments in Physics," *Journal of Research in Science Teaching*, 1971, 8, No. 1.

Piaget, Jean, "Development and Learning," *Journal of Research in Science Teaching*, 1964, 2, No. 3.

Welch, Wayne, W., "Correlates of Courses Satisfaction in High School Physics," *Journal of Research in Science Teaching*, 1969, 6, No. 1.

________. "Some Characteristics of High School Physics Students: Circa 1968," *Journal of Research in Science Teaching*, 1969, 6, No. 3.

Welch, Wayne W. and Walberg, H. J., "Are the Attitudes of Teachers Related to Declining Enrollments in Physics?" *Science Education*, 1967, 51, No. 5.

Yale, F. G., "Why are High School Students Avoiding the Physical Sciences?", *Science Education*, October 1966, 50, No. 4.

Unpublished Materials

Bautista, Leticia B., *The Relationship Between Intellectual Levels and Achievement in the Comprehension of Concepts Classified According to a Scheme Derived from the Piagetian Model*, Unpublished Doctoral Dissertation, The University of Oklahoma, 1974.

Johnson, Linda M., *Biology Concepts Taught Compared to the Intellectual Level of the Biology Student*, Unpublished M.Ed. Thesis, The University of Oklahoma, 1975.

Karplus, Robert, Director of Lawrence Hall of Science, University of California, Berkeley, comment made on June 24, 1976, at the American Association of Physics Teachers' Conference, University of Missouri, Rolla.

Lawson, Anton E., *Relationships Between Concrete and Formal Operational Science Subject Matter and the Intellectual Level of the Learner*, Unpublished Doctoral Dissertation, The University of Oklahoma, 1973.

McKinney, Larry, State Science Consultant, State of Oklahoma, personal correspondence.

Renner, John W., et al., Interviewing Protocols for Tasks to Determine Levels of Thought, Unpublished Manuscript, Cognitive Analysis Project, The University of Oklahoma, 1976.

APPENDIX A

CLASSIFICATION OF MAJOR PHYSICS CONCEPTS

Text: P.S.S.C. Physics

Chapter	Concepts	L	P	Operations									
				Cl	OC	S	CI	CO	PR	SV	RI	E	P
5	Acceleration is the rate of change of velocity	F	PR	X	X	X	X	X	X	X	X	X	
6	Vectorial quantities, such as acceleration and velocity, can either be added or resolved into component parts	F	FR PR	X	X	X	X	X	X	X	X	X	
7	Matter is composed of elements. Conservation of mass	F	PR CN	X	X	X	X	X	X	X	X	X	
8	The atomic and molecular structure of matter	F	PR	X	X	X	X	X	X	X	X	X	
9	The kinetic theory of gases	F	PR P	X	X	X	X	X	X	X	X	X	X
11	Properties of light	F	PR	X	X	X	X	X	X	X	X	X	
12	Mirror formulae for the reflection of light	F	PR	X	X	X	X	X	X	X	X	X	
13	Lens formulae for the refraction of light	F	PR	X	X	X	X	X	X	X	X	X	
14	The particle model of light	F	PR	X	X	X	X	X	X	X	X	X	
15	Properties of wave pulses along springs	F	PR	X	X	X	X	X	X	X	X	X	

P.S.S.C. Physics--Continued

Chapter	Concepts	L	P	Operations									
				CL	OC	S	CI	CO	PR	SV	RI	E	P
16	Properties of water waves	F	PR	X	X	X	X	X	X	X	X	X	
17	Interference of water waves	F	PR	X	X	X	X	X	X	X	X	X	
18	Interference and diffraction of light	F	PR	X	X	X	X	X	X	X	X	X	
19	Newton's first and second laws of motion	F	PR	X	X	X	X	X	X	X	X	X	
20	Properties of projectile, circular and simple harmonic motions	F	PR FR	X	X	X	X	X	X	X	X	X	
21	Kepler's laws and Newton's law of universal gravitation	F	PR	X	X	X	X	X	X	X	X	X	
22	Conservation of momentum	F	PR CN	X	X	X	X	X	X	X	X	X	
23	Work done measures the transfer of kinetic energy	F	PR CN	X	X	X	X	X	X	X	X	X	
24	Gravitational potential energy	F	PR CN	X	X	X	X	X	X	X	X	X	
25	Conservation of energy	F	PR CN	X	X	X	X	X	X	X	X	X	
26	Electrostatics and conductivity	F	PR CN	X	X	X	X	X	X	X	X	X	

P.S.S.C. Physics--Continued

Chapter	Concepts	L	P	Operations									
				CL	OC	S	CI	CO	PR	SV	RI	E	P
27	Coulomb's law	F	PR	X	X	X	X	X	X	X	X	X	
28	Electrical potential energy	F	PR	X	X	X	X	X	X	X	X	X	
29	Electrical circuit theory	F	PR CN	X	X	X	X	X	X	X	X	X	
30	Electromagnetism and magnetic fields	F	PR	X	X	X	X	X	X	X	X	X	
31	Electromagnetic induction and electromagnetic waves	F	PR FR	X	X	X	X	X	X	X	X	X	
32	Rutherford's atomic model	F	PR P	X	X	X	X	X	X	X	X	X	X
33	Quantum theory	F	PR P	X	X	X	X	X	X	X	X	X	X
34	Quantum theory and atomic structure	F	PR P	X	X	X	X	X	X	X	X	X	X

SOURCE: W. L. Haber-Schaim, et al., P.S.S.C. Physics, 2nd ed, (Boston: D. C. Health and Co., 1965)

CLASSIFICATION OF MAJOR PHYSICS CONCEPTS

Text: Investigations in Physics

				Operations									
Chapter	Concepts	L	P	CL	OC	S	CI	CO	PR	SV	RI	E	P
2	Gravitational field	F	PR	X	X	X	X	X	X	X	X	X	
3	Properties of the vectorial quantities, acceleration and velocity	F	PR	X	X	X	X	X	X	X	X	X	
4	Newton's second law of motion	F	ME PR	X	X	X	X	X	X	X	X	X	
5	Newton's first law of motion	F	ME PR FR	X	X	X	X	X	X	X	X	X	
6	Conservation of momentum and Newton's third law of motion	F	ME PR CN FR	X	X	X	X	X	X	X	X	X	
7	Work and conservation of energy	F	CN PR	X	X	X	X	X	X	X	X	X	
8	First and second laws of thermodynamics	F	CN PR	X	X	X	X	X	X	X	X	X	
9	The kinetic theory of gases	F	P PR	X	X	X	X	X	X	X	X	X	X
10	Simple harmonic motion	F	PR	X	X	X	X	X	X	X	X	X	

Investigations in Physics--Continued

Chapter	Concepts	L	P	Operations									
				Cl	OC	S	CI	CO	PR	SV	RI	E	P
11	Properties of wave motion	F	PR	X	X	X	X	X	X	X	X	X	
12	Properties of light and the wave model of light	F	PR	X	X	X	X	X	X	X	X	X	
13	Coulomb's law and the electric field	F	PR	X	X	X	X	X	X	X	X	X	
14	Electric currents and circuit theory	F	PR CN	X	X	X	X	X	X	X	X	X	
15	Electromagnetism	F	PR	X	X	X	X	X	X	X	X	X	
16	Electromagnetic induction	F	PR	X	X	X	X	X	X	X	X	X	
17	Electromagnetic waves and relativity	F	PR FR	X	X	X	X	X	X	X	X	X	
18	Quantum theory	F	P PR	X	X	X	X	X	X	X	X	X	X
19	Atomic models--Bohr --Schrodinger	F	PR P	X	X	X	X	X	X	X	X	X	X
20	Nuclear models and particles	F	PR P	X	X	X	X	X	X	X	X	X	X

SOURCE: John W. Renner and Harry B. Packard, Investigations in Physics, (Chicago: Lyons and Carnahan, 1974)

CLASSIFICATION OF MAJOR PHYSICS CONCEPTS

Text: Physics: (Teacher's Edition)

				Operations									
Chapter	Concepts	L	P	CL	OC	S	CI	CO	PR	SV	RI	E	P
2	Speed is the rate of change of position	F	PR	X	X	X	X	X	X	X	X	X	
3	Acceleration is the rate of change of speed	F	PR	X	X	X	X	X	X	X	X	X	
4	Newton's second law of motion	F	PR	X	X	X	X	X	X	X	X	X	
5	Newton's law of universal gravitation	F	PR	X	X	X	X	X	X	X	X	X	
6	Newton's third law of motion	F	PR ME	X	X	X	X	X	X	X	X	X	
7	Vectorial quantities, such as velocity, can either be added or resolved into component parts	F	PR FR	X	X	X	X	X	X	X	X	X	
8	Properties of projectile and circular motion	F	FR PR	X	X	X	X	X	X	X	X	X	
9	Some electrical and magnetic phenomena have similar properties	F	PR	X	X	X	X	X	X	X	X	X	
10	Electromagnetism	F	PR	X	X	X	X	X	X	X	X	X	

Physics: (Teacher's Edition)--Continued

Chapter	Concepts	L	P	Operations Cl	OC	S	CI	CO	PR	SV	RI	E	P
11	Conservation of momentum	F	PR CN	X	X	X	X	X	X	X	X	X	
12	Work and the conservation of energy	F	CN PR	X	X	X	X	X	X	X	X	X	
13	Heat, as a form of energy, is conserved	F	CN PR	X	X	X	X	X	X	X	X	X	
14	The kinetic theory of gases	F	P PR	X	X	X	X	X	X	X	X	X	X
15	Internal energy and kinetic energy	F	P CN PR	X	X	X	X	X	X	X	X	X	X
16	Electrical energy	F	P CN	X	X	X	X	X	X	X	X	X	X
17	Elementary electronic charge	F	CN PR	X	X	X	X	X	X	X	X	X	
18	Mirror formulae for the reflection of light	F	PR	X	X	X	X	X	X	X	X	X	
19	The particle model of light can explain some properties of refracted light	F	PR	X	X	X	X	X	X	X	X	X	
20	Wave model of light	F	PR	X	X	X	X	X	X	X	X	X	

Physics: (Teacher's Edition)--Continued

Chapter	Concepts	L	R	Operations									
				Cl	OC	S	CI	CO	PR	SV	RI	E	P
21	The wave model of light explains the interference of light	F	PR	X	X	X	X	X	X	X	X	X	
22	Electromagnetic waves	F	PR	X	X	X	X	X	X	X	X	X	
23	The speed lf light is constant and relativity	F	PR FR	X	X	X	X	X	X	X	X	X	
24	Rutherford's atomic model	F	P PR	X	X	X	X	X	X	X	X	X	X
25	Quantum theory and atomic structure	F	PR	X	X	X	X	X	X	X	X	X	

SOURCE: Irwin Genzer and Philip Youngner; Physics: Teacher's Edition (New Jersey: Silver Burdett, 1973)

CLASSIFICATION OF MAJOR PHYSICS CONCEPTS

Text: Project Physics: Text

				Operations									
Chapter	Concepts	L	P	Cl	OC	S	CI	CO	PR	SV	RI	E	P
1	Acceleration is rate of change of speed	F	PR	X	X	X	X	X	X	X	X	X	
3	Newton's three laws of motion	F	ME FR PR	X	X	X	X	X	X	X	X	X	
4	Speed, velocity and acceleration relationships in projectile and circular motion	F	PR FR	X	X	X	X	X	X	X	X	X	
7	Kepler's three laws of planetary motion	F	PR	X	X	X	X	X	X	X	X	X	
8	Newton's law of universal gravitation	F	PR	X	X	X	X	X	X	X	X	X	
9	Conservation of momentum	F	PR CN	X	X	X	X	X	X	X	X	X	
10	Energy conservation	F	PR CN	X	X	X	X	X	X	X	X	X	
11	Kinetic theory of gases	F	P PR	X	X	X	X	X	X	X	X	X	X
12	Properties of waves	F	PR	X	X	X	X	X	X	X	X	X	
13	Properties of light can be explained with the wave model	F	PR	X	X	X	X	X	X	X	X	X	

Text: Project Physics: Text--Continued

				Operations									
Chapter	Concepts	L	P	Cl	OC	S	CI	CO	PR	SV	RI	E	P
14	Electric and magnetic fields	F	CN PR	X	X	X	X	X	X	X	X	X	
15	Electromagnetism	F	PR	X	X	X	X	X	X	X	X	X	
16	Electromagnetic waves	F	PR	X	X	X	X	X	X	X	X	X	
17	Faraday's laws	F	PR CN	X	X	X	X	X	X	X	X	X	
18	Photons and quantum theory	F	PR	X	X	X	X	X	X	X	X	X	
19	Rutherford--Bohr atomic model	F	P PR	X	X	X	X	X	X	X	X	X	X
20	Quantum mechanics	F	PR P	X	X	X	X	X	X	X	X	X	X

SOURCE: Gerald Holton, Fletcher G. Watson; and F. James Rutherford, Project Physics: Text, (New York: Holt, Rinehart, Winston, 1975)

CLASSIFICATION OF MAJOR PHYSICS CONCEPTS

Text: The World of Physics

Chapter	Concepts	L	P	Operations									
				Cl	OC	S	CI	CO	PR	SV	RI	E	P
1	Newton's third law of motion	F	PR ME	X	X	X	X	X	X	X	X	X	
2	Conservation of potential and kinetic energies	F	PR CN	X	X	X	X	X	X	X	X	X	
3	Atomic and molecular structure of matter	F	PR	X	X	X	X	X	X	X	X	X	
4	Newton's first law of motion	F	FR PR	X	X	X	X	X	X	X	X	X	
5	Newton's second law of motion	F	PR	X	X	X	X	X	X	X	X	X	
6	Properties of projectile and circular motions	F	PR FR	X	X	X	X	X	X	X	X	X	
7	Conservation laws	F	PR CN	X	X	X	X	X	X	X	X	X	
8	Planetary, gravitational, electrostatic and simple harmonic motions involve forces which do not depend on the speed of the object	F	PR	X	X	X	X	X	X	X	X	X	
9	Magnetic and frictional forces	F	PR	X	X	X	X	X	X	X	X	X	

The World of Physics--Continued

				Operations									
Chapter	Concepts	L	P	Cl	OC	S	CI	CO	PR	SV	RI	E	P
10	Internal energy	F	CN PR	X	X	X	X	X	X	X	X	X	
11	Atomic and molecular models for matter	F	ME PR	X	X	X	X	X	X	X	X	X	
12	First and second laws of thermodynamics	F	P PR CN	X	X	X	X	X	X	X	X	X	X
13	Electrical circuit theory	F	PR	X	X	X	X	X	X	X	X	X	
14	Characteristics of water waves	F	PR	X	X	X	X	X	X	X	X	X	
15	Properties of sound waves	F	PR	X	X	X	X	X	X	X	X	X	
16	Wave model of light	F	PR	X	X	X	X	X	X	X	X	X	
17	Quantum mechanics	F	P PR	X	X	X	X	X	X	X	X	X	X

SOURCE: Robert Hulsizer and David Lazarus, The World of Physics, (Menlo Park, California: Addison-Wesley Publishing Co., 1972)

CLASSIFICATION OF MAJOR PHYSICS CONCEPTS

Text: Modern Physics: Teacher's Edition

				Operations									
Chapter	Concepts	L	P	Cl	OC	S	CI	CO	PR	SV	RI	E	P
1	Conservation of matter and energy	F	CN PR	X	X	X	X	X	X	X	X	X	
3	Ressolution and composition of forces	F	PR ME	X	X	X	X	X	X	X	X	X	
4	Newton's three laws of motion. Newton's law of universal gravitation	F	ME PR	X	X	X	X	X	X	X	X	X	
5	Properties of circular and simple harmonic motions	F	CN PR	X	X	X	X	X	X	X	X	X	
6	Conservation of mechanical energy	F	PR CN	X	X	X	X	X	X	X	X	X	
7	Kinetic theory of gases	F	CN PR P	X	X	X	X	X	X	X	X	X	X
8	Thermal energy	F	P PR	X	X	X	X	X	X	X	X	X	X
9	First and second laws of thermodynamics	F	P CN PR	X	X	X	X	X	X	X	X	X	X
10	Properties of water waves	F	PR	X	X	X	X	X	X	X	X	X	

Modern Physics: Teacher's Edition--Continued

Chapter	Concepts	L	P	Operations									
				Cl	OC	S	CI	CO	PR	SV	RI	E	P
11	Properties of sound waves	F	PR	X	X	X	X	X	X	X	X	X	
12	The wave-particle duality characteristics of light	F	PR	X	X	X	X	X	X	X	X	X	
13	Reflection of light and mirror formulae	F	PR	X	X	X	X	X	X	X	X	X	
14	Refraction of light and the lens formulae	F	PR	X	X	X	X	X	X	X	X	X	
15	Properties of light can be explained with the wave model of light	F	PR	X	X	X	X	X	X	X	X	X	
16	Electrostatics and Coulomb's law	F	PR	X	X	X	X	X	X	X	X	X	
17	Electrical circuit theory	F	PR	X	X	X	X	X	X	X	X	X	
18	The heating effect of an electric current and electrolysis	F	PR	X	X	X	X	X	X	X	X	X	
19	A magnetic field encircles an electric charge in motion	F	PR	X	X	X	X	X	X	X	X	X	
20	Electromagnetic induction	F	PR	X	X	X	X	X	X	X	X	X	
21	Properties of alternating currents	F	PR	X	X	X	X	X	X	X	X	X	

Modern Physics: Teacher's Edition--*Continued*

				Operations									
Chapter	Concepts	L	P	Cl	OC	S	CI	CO	PR	SV	RI	E	P
22	Properties of semiconductors	F	PR	X	X	X	X	X	X	X	X	X	
23	Atomic and nuclear structures	F	P										
			CN										
			PR	X	X	X	X	X	X	X	X	X	X
24	Radioactivity and nuclear reactions	F	PR										
			P										
			CN	X	X	X	X	X	X	X	X	X	X
25	Bohr's atomic model and quantum theory	F	PR										
			CN										
			P	X	X	X	X	X	X	X	X	X	X

SOURCE: John E. Williams, et al., *Modern Physics: Teacher's Edition* (New York: Holt, Rinehart, Winston, Inc., 1972)

APPENDIX B

IDENTIFICATION OF CONCRETE OPERATIONAL CONCEPTS

AND RELATED FORMAL OPERATIONAL CONCEPTS

Text: P.S.S.C. Physics

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
11	Some objects give off their own light, others do not. Some objects are colored, others are transparent. Light bounces back off flat, smooth, shiny surfaces. When objects are placed, half in water and half in air, they appear to bend. Light seems to spread out and form a pattern of light and dark lines when it passes through a narrow gap.	Absorption, transmission, and reflection of light. Specular and diffuse reflection. Infrared and ultraviolet light. Propagation of light. Speed of sound compared with the speed of light.	**Properties of light.**
12	Beams of light can pass through each other. Shadows of objects can have sharp or fuzzy edges. Light bounces back off mirrors. Parallel light reflected off curved mirrors comes to a focus.	Rays of light. Binocular vision. Laws of reflection. Virtual and real images formed by mirrors. Focus point and focal length.	**Mirror formulae.**

Text: P.S.S.C. Physics--Continued

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
13	Light is bent when it passes from one medium to another.	Laws of refraction. Snell's law. Refractive index. Reversibility of light paths. Total internal reflection. Dispersion. Converging lenses--focal length. Real and virtual images formed by lenses.	Lens formulae.
15	Pulses travel down springs. Pulses pass through each other. Pulses can be reflected. Pulses can travel from one spring to another.	The pulse travels at right angles to the direction of motion of the parts of the spring. Superposition of pulses. Pulses are reflected, sometimes with changes in phase, amplitude and speed. Pulses can be transmitted into a different spring with changes in amplitude and speed. Internal resistance of springs.	Properties of two-dimensional waves.

Text: P.S.S.C. Physics--Continued

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
16	Water waves can travel in circles or straight lines. Circular and straight waves bounce back off straight barriers. Water waves get closer together when they travel from deep to shallow water. Straight waves bend out after passing through a narrow slit.	Laws of reflection for straight waves. Image point of circular waves reflected off a straight barrier. Periodic waves ($v = f\lambda$) Refraction of water waves --Snell's law --refractive index Dispersion of waves. Diffraction of waves in terms of wavelength, and slit width. Relationship between waves and properties of light.	Properties of three-dimensional waves and the wave model of light.
19	Forces are pushes and pulls.	Galileo's law of inertia. $\frac{\Delta v}{\Delta t}$ = constant if force and mass are constant. $\frac{\Delta v}{\Delta t} \propto F$ if mass is constant. $F \Delta t = m \Delta v$. Inertial and gravitational mass. Vectorial addition of forces.	Newton's first and second law of motion.

Text: P.S.S.C. Physics--Continued

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
26	Two like rods rubbed with silk or fur repel each other. Two unlike rods rubbed with silk or fur attract each other.	Like charged objects repel each other. Unlike charged objects attract each other. Positive and negative charges. All conductors contain freely moving charges; insulators do not. Electrostatic induction. Electric current. Ionized gases behave like conductors. Electrolysis.	Electrostatics and conductivity.

SOURCE: Uri Haber-Schaim, et al., P.S.S.C. Physics, 2nd edition, (Boston: D.C. Heath and Co., 1965)

IDENTIFICATION OF CONCRETE OPERATIONAL CONCEPTS AND RELATED FORMAL OPERATIONAL CONCEPTS

Text: Investigations in Physics

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
2	Bodies fall down because of gravity. The center of gravity of an object is the one point at which the object can be balanced when placed horizontally. A push or pull is a force. Forces move objects unless other forces are applied to keep them from moving.	Falling objects move toward the center of the earth. The force of gravity increases a falling object's velocity. Weight and mass. Centripetal acceleration. The force of gravity is inversely proportional to the square of the distance between the earth and an object. Newton's law of universal gravitation.	Gravitational field.
3	The speed of an object is how fast it moves.	$\overline{V} = \frac{\Delta \overline{s}}{\Delta t}$ Instantaneous and average velocity. $\overline{a} = \frac{\Delta \overline{v}}{\Delta t}$	Vectorial quantities--velocity and acceleration.

Investigations in Physics--Continued

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
3 (con't)		Quantities of acceleration and speed can be derived from distance-time and speed-time graphs. Constant acceleration formulae. Gravitational acceleration. Terminal velocity. Projectile motion. Composition and resolution of velocity. Centripetal acceleration. Free-fall - "weightlessness."	
4	Forces are pushes and pulls. Forces move objects in definite directions. Forces have different magnitudes.	$F \propto a$ if mass is constant. $a \propto \frac{1}{m}$ is force is Gravitational field strength. Impulse. Centripetal force. Universal gravitation. Kepler's three laws.	Newton's second law of motion.

Investigations in Physics--Continued

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
5	Forces balance one another when a body is in equilibrium. A person's interpretation of any given event depends upon the position from which he views the event.	Static, dynamic and rotational equilibrium. Torque. Relative motion and frames of reference. Inertia. Gravitational and inertial mass.	Newton's first law of motion.
7	People use energy when they run, play football or otherwise exercise. People consume energy. Cars and other objects consumer energy. Work is done when objects are moved.	Work = distance X component of the force in the direction of motion. Work done = transfer of energy. Kinetic energy. Potential energy. Forms of energy. Power.	Work and conservation of energy.
8	Heat will result when work is done. Hot metals expand; cold contract. Heating an object either changes the temperature of the object or changes its state.	Difference between heat and temperature. Heat capacity. Heat of fusion and vaporization. Mechanical equivalent of heat. Heat and internal energy.	The first and second laws of thermodynamics.

Investigations in Physics--Continued

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
9	Hot air expands; cold air contracts.	Properties of gases. Gas pressure. Boyle's law. Avogadro's hypothesis. Charle's law. General gas law. Relationship between kinetic energy and temperature of a gas.	Kinetic theory of gases.
11	There are both straight and circular waves.	Law of reflection for waves. Law of refraction for waves. Refractive index. Dispersion. Standing waves in terms of wave length and nodal points. Superposition and interference of waves. Phase difference between waves.	Properties of waves.
12	Light bounces back evenly off smooth surfaces. Objects appear to change shape when placed half in one medium and half in another medium. Light beans bend by different	Laws of reflection. Focus point of curved mirrors. Law of refraction--Snell's law. Focal point of lenses.	Properties of light and the wave model for light.

Investigations in Physics--Continued

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
12 (con't)	amounts when passing from air into glass at different angles	Lens formulae. Wave model for light. Interference of light. Illumination explained in terms of wave model for light. Polarization.	
13	Rubbed objects can attract or repel each other.	Conservation of electric charge. Lines of force. Electric energy. Electric potential.	Coulomb's law and the electric field.
14	Electricity flows along electric circuits.	Electric charges. Electric current. Potential difference. Ohm's law. Electromotive force. Heating effect of an electric current. Properties of electric currents. Properties of batteries. Series and parallel circuits and the relationship between potential difference, current, and resistance.	Electric currents and circuits.

Investigations in Physics--Continued

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
15	Compasses deflect when brought close to current carrying wires.	Magnetic field. Electric and magnetic fields effect charges. A current carrying wife experiences a force in a magnetic field. Ampere. Hall effect.	Electromagnetism.
16	A current in one circuit can induce a current in a nearby circuit.	Lenz's law. Faraday's law. Alternating currents.	Electromagnetic induction.

SOURCE: John W. Renner and Harry B. Packard, Investigations in Physics (Chicago: Lyons and Carnahan, 1974)

IDENTIFICATION OF CONCRETE OPERATIONAL CONCEPTS
AND RELATED FORMAL OPERATIONAL CONCEPTS

Text: Physics: Teacher's Edition

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
18	Light beams bounce back evenly off mirrors. Steel balls bounce back regularly off metal plates. Images are formed by mirrors. Light beams focus to a point after reflection off curved mirrors.	Propagation of light rays. Illumination of light obeys the inverse square law. Specular and diffuse reflection. Laws of reflection. The particle model for light. Virtual images formed by reflection. Reflection of light rays from curved mirrors.	Mirror formulae.
20	Pulses travel down springs. Pulses can pass through each other. Pulses can be reflected. Pulses can travel from one spring to another. Circular water waves. Circular and straight water waves are reflected off straight barriers.	Longitudinal and transverse waves. Partial reflection and transmission of pulses with subsequent change of phase. Huygen's principle. Image point of reflected circular waves.	Wave model of light.

Physics: Teacher's Edition--Continued

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
20 (con't)	Straight waves bend out after passing through narrow slits.	Law of reflection for straight waves. Velocity of waves. ($v = f\lambda$) Refraction of waves--Snell's law. Dispersion. Diffraction of waves and the relationship between wavelength and slit width.	
21	Two pulses traveling along a spring can add together to make one large pulse.	Superposition of pulses and the motion of particles in relation to the direction of propagation. Standing waves. Frequency effects the interference pattern of waves. Interference patterns of light.	The interference of light with one and two slits.

SOURCE: Irwin Genzer and Philip Youngner, Physics: Teacher's Edition, (New Jersey: Silver Burdett, 1973)

IDENTIFICATION OF CONCRETE OPERATIONAL CONCEPTS AND RELATED FORMAL OPERATIONAL CONCEPTS

Text: Project Physics: Text

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
3	Forces move things. When forces balance each other the object is in equilibrium.	Static equilibrium. Vectorial addition of forces. Vectorial quantities. Acceleration. Inertia. Mass and weight.	Newton's three laws of motion.
12	Pulses travel down springs. Circular waves move out from vibrating sources. Overlapping circular waves create an interference pattern. Straight waves spread out around the edges of objects and after passing through narrow slits. Pulses bounce back upside down off barriers. Circular and straight waves bounce back off straight barriers.	Longitudinal and transverse waves. Spring particles move at right angles to the direction of propagation of the wave. Periodic waves ($v = f\lambda$) - period. Phase difference in waves. Superposition principle. Constructive and destructive interference. Interference patterns and the relationship with wavelength, separation and distance.	Properties of waves.

Project Physics: Text--Continued

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
12 (con't)		Formation of standing waves. Huygen's principle. Wavelength and slit width effect diffraction patterns. Laws of reflection. Refraction of waves and Snell's law. The spectrum of sound waves.	
13	Light beams travel in straight lines	Laws of reflection. Refraction and the effect of the speed of the light ray. Interference and diffraction patterns verify the wave model. Spectra. Dispersion. Polarization of waves.	Properties of light.
14	Rubbed objects can repel or attract each other. A compass needle deflects when near a current carrying wire.	Electrostatic charges. Coulomb's law. Electrostatic induction. Magnetic force field. Electric force fields. Gravitational force fields.	Electric and magnetic fields.

Project Physics: Text--Continued

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
14 (con't)		Elementary electric charges. Conservation of electric charges. Electric currents and potential difference. Electrical power. Electromagnetism. Parallel current-carrying wires repel or attract each other. Magnetic fields effect moving charges.	

SOURCE: Gerald Holton, Fletcher G. Watson; and F. James Rutherford, Project Physics: Text (New York: Holt, Rinehart, Winston, 1975)

IDENTIFICATION OF CONCRETE OPERATIONAL CONCEPTS

AND RELATED FORMAL OPERATIONAL CONCEPTS

Text: The World of Physics

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
9	A current-carrying wire can deflect a compass needle.	Electric currents produce magnetic fields. Electric current. A magnetic force exists between moving charges. Electromagnetic induction. Electromagnetic field. Bernoulli effect.	Magnetic and frictional forces.
14	Pulses travel down springs. Water waves spread out in circles. Straight waves bend out after passing through narrow slits.	Energy, momentum and propagation properties of waves. Huygen's principle. The motion of particles in transverse and longitudinal waves. Periodic wave properties. Laws of reflection and refraction for waves. The effect of wavelength and slit width on the diffraction of waves.	Characteristics of waves.

The World of Physics--Continued

Chapter	Concrete Concepts	Minor Formal Concepts	Major Formal Concepts
14 (con't)		Constructive and destructive interference. Stationary waves. Resonance.	
16	Light bends when it passes from air into glass.	$v = f\lambda$ Photoelectric effect. Light intensity obeys the inverse-square law. Shadow formation can be explained by the ray model. Diffraction patterns of light can be explained by the wave model. Real and virtual images formed by reflection and refraction. Lens formulae for refraction.	Wave model of light.

SOURCE: Robert Hulsizer and David Lazarus, The World of Physics, (Menlo Park, California: Addison-Wesley Publishing Co., 1972)

APPENDIX C

APPENDIX C

Explanations of Concepts Which Were Abbreviated in Appendices A and B

Many of the concepts in Appendices A and B were abbreviated. Explanations of these concepts are given below. Whenever a concept was repeated in a textbook which had already been explained from another textbook, an additional similar explanation was not given.

Textbook: P.S.S.C. Physics[1]

Chapter 8. Abbreviated Concept: Atomic and molecular structure of matter.

> Explanation: "Atoms are the building blocks of matter." "It is the smallness of an atom that makes atoms so difficult to detect with unaided senses. On the other hand, it is the very smallness of size and massiveness of number which enable us to explain all the wonders of matter."[2]

Chapter 9. Abbreviated Concept: The kinetic theory of gases.

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[1] Haber-Schaim, P.S.S.C. Physics.

[2] Ibid., p. 132.

Explanation: "Widely spaced molecules, moving every which way in empty space with speeds a bit faster than sound, colliding and rebounding as they move--that is our model of a gas."[3]

Chapter 11. Abbreviated Concept: Properties of light.

Explanation: "(There is) a basic difference between incandescent sources and other sources. In the former, changes in brightness, temperature, and color seem to be closely linked, while in the latter the color of the source depends mainly on the nature of the material and does not vary with brightness."[4]

". . . we become aware of clear materials . . . partly because they reflect as well as transmit light and partly because some of the light is absorbed."[5]

"All bodies, whether transparent or opaque, reflect some of the light that falls upon them."[6]

". . . heat (infrared) radiation is . . . a form of (invisible) light."[7] ". . . ultraviolet light (is) invisible (and) harmful to the human eye."[8]

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[3] Ibid., p. 163.

[4] Ibid., p. 189.

[5] Ibid.

[6] Ibid., p. 191.

[7] Ibid., p. 193.

"Light generally travels in straight lines (but light also) bends slightly as it passes the edge of an obstacle."[9]

Chapter 12. Abbreviated Concept: Mirror formulae for the reflection of light.

Explanation: ". . . once we know from experiment that images are actually formed, tracing a few rays in accord with the laws of reflection will lead us to the relations between object and image."[10]

$$\frac{Hi}{Ho} = \frac{Si}{f} = \frac{f}{So}$$

(Hi = image height
Ho = object height
Si = image distance
So = object distance
f = focal length)

Chapter 13. Abbreviated Concept: Lens formulae for the refraction of light.

Explanation: ". . . lenses obey the same equation relating image distance, focal length and object distance as do mirros: $Si\ So = f^2$."[11]

Chapter 14. Abbreviated Concept: The particle model of light.

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[8] Ibid., p. 194.

[9] Ibid., p. 195.

[10] Ibid., p. 212.

[11] Ibid., p. 236.

Explanation: Light consists of very small, rapidly moving particles which undergo elastic collisions.[12] This is the particle model of light.

Chapter 15. Abbreviated Concept. Properties of wave pulses along springs.

Explanation: "A wave, a thing which is not itself a particle of matter, can go from one place to another."[13]

". . . any pulse moves undisturbed at constant speed along the spring and . . . the spring itself moves only at right angles to the motion of the pulse."[14]

". . . two pulses pass through each other without being altered. . ."[15] "To find the form of the total wave disturbance at any time, we add at each point the displacements belonging to each pulse that is passing through the medium . . . i.e., the Superposition Principle."[16]

When a pulse is reflected from a fixed end it comes back upside down, but with the same shape.[17]

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[12] Ibid., pp. 241-245.

[13] Ibid., p. 255.

[14] Ibid., p. 257.

[15] Ibid.

[16] Ibid., p. 259.

[17] Ibid., p. 261.

". . . when a pulse is sent along a spring towards a junction with a second spring . . . the whole pulse is reflected upside down whenever the second spring is very much heavier than the first. As the second spring is replaced by lighter and lighter springs, the reflected pulse becomes small and a larger and larger transmitted pulse is observed to go beyond the junction. . . . If the second spring is made lighter (than the first), reflection sets in again, this time with the reflected pulse right side up. The lighter the second spring, the larger is the reflected pulse."[18]

Chapter 16. Abbreviated Concept: Properties of water waves. Explanation: "Just as the formation of images by mirrors followed from the laws of reflection in optics, so does the corresponding formation of images by 'mirrors' in the ripple tank."[19]

"The speed of propagation of a periodic wave is the product of the frequency and the wavelength."[20]

For water waves the "index of refraction is equal to the ratio of the speed of propagation in the first medium to that in the second."[21]

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[18] *Ibid.*, p. 263.

[19] *Ibid.*, p. 271.

[20] *Ibid.*, p. 272.

[21] *Ibid.*, p. 275.

"The index of refraction of waves depends slightly on the frequency."[22] ". . . waves are strongly diffracted when they pass through an opening of size comparable to their wavelength, and there is hardly any diffraction if the wavelength is very small compared to the width of the opening."[23]

Chapter 17. Abbreviated Concept: Interference of water waves.

Explanation: An interference pattern is constructed by superimposing the waves from two sources.[24] "With different wavelengths or different separation of the sources the interference pattern changes in detail."[25] A determination of the wavelength can be made from the formula: $\lambda = \frac{d\,x}{L(n-\frac{1}{2})}$

λ = wavelength
d = separation of sources
x = perpendicular distance to the point bisecting the line between the sources
n = number of nodal lines[26]

A phase difference between the sources affects the interference pattern.[27]

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[22] Ibid., p. 276.

[23] Ibid., p. 278.

[24] Ibid., p. 284.

[25] Ibid., p. 285.

[26] Ibid., p. 289.

[27] Ibid., p. 291.

Chapter 18. Abbreviated Concept: Interference and diffraction of light.

Explanation: To obtain an interference pattern with light, the sources must be in phase.[28]

"The analysis of light by locating maxima and minima in an interference pattern makes it possible to characterize the light accurately in terms of wavelength."[29]

$$\lambda = \frac{d\,\Delta x}{L}$$

λ = wavelength of light
d = separation of slits
Δx = separation of nodal lines
L = distance of slits to observer

The diffraction pattern of light obtained with a single slit can be explained using the Huygen's principle.[30]

Single-slit diffraction affects resolution.[31] Interference occurs with both reflected and transmitted light through thin films.[32]

Chapter 19. Abbreviated Concept: Newton's first and second laws of motion.

Explanation: "Galileo's law of intertia (Newton's first law of motion) tells us that an object on which no force act moves with unchanging velocity."[33]

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[28] *Ibid*., p. 299.

[29] *Ibid*., p. 300.

[30] *Ibid*., p. 302.

[31] *Ibid*., pp. 305-306.

[32] *Ibid*., pp. 307-310.

"The relation $F\Delta t = M\Delta V$ tells us how the change in velocity V is related to the initial mass, M, to the cause of the motion, F, and to the time, t that the force acts. This relation embodies Newton's law of motion."[34]

Chapter 20. Abbreviated Concepts: Properties of projectile circular and simple harmonic motions.

Explanation: the path of a freely moving projectile is parabolic.

"The horizontal component of velocity never changes and the vertical component undergoes a uniform change at the rate $\frac{\Delta Vg}{\Delta t} = -g$."[35]

(ΔVg = change in vertical velocity
Δt = time interval
g = acceleration due to gravity).

A body moving in a uniform, circular path has acceleration, $\bar{a}$, and centripital force $\bar{F}$.

$$\bar{a} = \frac{-4\pi^2\bar{R}}{T^2} \text{ and } \bar{F} = \frac{-4\pi^2 m\bar{R}}{T^2}.$$[36]

($\bar{R}$ = radius, position vector
m = mass of the body
T = period)

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[33] Ibid., p. 323.

[34] Ibid., p. 328.

[35] Ibid., p. 340.

[36] Ibid., p. 343.

Bodies undergoing simple harmonic motion have linear resisting forces, i.e., $\overline{F} = -k\overline{x}$.[37]

($\overline{F}$ = restoring force
k = constant of proportionality
$\overline{X}$ = displacement from equilibrium)

Newton's laws of motion are invalid in accelerated frames of reference.[38]

Chapter 21. Abbreviated Concept: Kepler's laws and Newton's law of universal gravitation.

Explanation: "Kepler's three laws:

1. Each planet moves in an elliptical path with the sun at one focus.
2. The line joining the sun and the planet sweeps out equal areas in equal times.
3. The ratio $\frac{R^3}{T^2}$ is the same for all planets."[39]

(R = mean radius of planet's orbit
T = period of revolution)

"The expression $F = \frac{Gm_1m_2}{R^2}$ summarizes Newton's law of universal gravitation. Any two bodies attract each other with forces (F) inversely proportional to the square of the distance (R) between them.[40]
(G = universal gravitation constant)

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[37] *Ibid.*, pp. 347-348.

[38] *Ibid.*, p. 352.

[39] *Ibid.*, pp. 365-366.

[40] *Ibid.*, p. 371.

Chapter 22. Abbreviated Concept: Conservation of momentum.

Explanation: The law of conservation states that the total momentum, $\overline{P}$, is constant, i.e., $\Delta \overline{P} = 0$.[41] This law applies to any number of interacting bodies in any isolated system.[42]

Chapter 24. Abbreviated Concept: Gravitational potential energy.

Explanation: "Potential energy, U_{λ} at separation, λ is

$$U_{\lambda} = \frac{-GMm}{\lambda}.$$

(G = universal gravitation constant
M,m = masses of the objects)

"For any motion under the influence of the gravitational potential attraction alone, what is gained in potential energy as the bodies separate is paid for by reduction in kinetic energy."[43]

Chapter 25. Abbreviated Concept: Conservation of energy.

Explanation: "To the best of our knowledge, the total energy in a region changes only when an exchange of energy occurs between the region and its surroundings. Then, if our region is the whole universe, we can expect no change of the total energy because, by definition, there is nothing outside the universe.

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[41] Ibid., p. 385.

[42] Ibid., pp. 390-391.

[43] Ibid., p. 434.

This assumption, that the total energy of the universe is constant, is the basis of most cosmological theories."[44]

Chapter 26. Abbreviated Concept: Electrostatics and conductivity.

Explanation: ". . . forces exerted by the two kinds of particles can cancel. When the effects of the positive and negative particles cancel exactly, we say the object is uncharged or electrically neutral . . . If we add some positive particles to an electrically neutral object, there is no longer a balance. The effect of the positive particles is greater than the effect of the negative particles; and we say the object is positively charged. We can also charge an object positively by removing some negative particles, leaving an excess of positive ones."[45]

"A flow of electric particles in a conductor is called an electric current."[46]

Chapter 27. Abbreviated Concept: Coulomb's law.

Explanation: The electrical force, F, between charges Q and q is "inversely proportional to the square of the separation, r, between the charges.

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[44] *Ibid.*, p. 457.

[45] *Ibid.*, pp. 465-466.

[46] *Ibid.*, p. 474.

$F = \frac{kQq}{r^2}$."[47]

(k = constant of proportionality)

Chapter 28. Abbreviated Concept: Electrical potential energy.

Explanation: Two charged bodies, Q and q, have an electric potential energy, $U = \frac{kQq}{r}$.

(r = separation
k = proportionality constant)

The potential energy, V due to the electric field of q is $V = \frac{kq}{r}$.[48]

(V = electric potential
r = distance
q = charge
k = proportionality constant)

Chapter 29. Abbreviated Concept: Electrical circuit theory.

Explanation: "The conservation of energy shows us that the sum of the potential differences is always equal to that applied EMF."[49]

Chapter 30. Abbreviated Concept: Electromagnetism and magnetic fields.

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[47] Ibid., p. 485.

[48] Ibid., p. 520.

[49] Ibid., p. 540.

Explanation: The magnetic force, F, on a piece of wire of length l, carrying a current, I, is proportional to $B_\perp$, the magnitude of the component of the magnetic field $\bar{B}$ perpendicular to the wire. $F = B_\perp I l$.[50]

"The circulation of $\bar{B}$ depends only on the total current passing through the surface bounded by the loop."[51]

Chapter 31. Abbreviated Concept: Electromagnetic induction and electromagnetic waves.

Explanation: ". . . the induced EMF, $\mathcal{E}$, is proportional to the rate of change of magnetic flux.

$\mathcal{E} = \frac{\Delta \phi_B}{\Delta t}$.[52]

($\Delta \phi_B$ = change of magnetic flux
Δt = time interval)

". . . light . . . is an electromagnetic disturbance in the form of waves."[53] "Electromagnetic radiation . . . is propagated with the speed of light and it arises from accelerated charges."[54]

Chapter 32. Abbreviated Concept: Rutherford's atomic model.

Explanation: "His (Rutherford's) model describes an atom as a miniature solar system with a core, or nucleus, at the center and a number of electrons around it. The nucleus is positively charged and carries almost all of the atomic mass. The light, negatively charged electrons revolve around the nucleus, held by . . . Coulomb's attraction. . . . Outside the atom, these negative electrons cancel the effect of the positive charge of the nucleus, so that the atom as a whole is neutral . . . the dimensions of the nucleus and of the electrons are assumed to be very small compared with the overall size of the atom. . . ."[55]

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[50] Ibid., p. 554.

[51] Ibid., p. 562.

[52] Ibid., p. 579.

[53] Ibid., p. 587.

[54] Ibid., p. 590.

Chapter 33. Abbreviated Concept: Quantum theory.

Explanation: "Waves of light proved to describe the probability of the appearance of certain particle-like photons, the particles of matter turn out to be governed by a wavelike quantity. Planck's constant controls the magnitudes involved in both cases. . . . The photon (is) governed in space and time by its electromagnetic wave of probability, the particle by its matter wave of probability--all with the de Broglie wavelength. . . ."[56]

Chapter 34. Abbreviated Concept: Quantum theory and atomic structure.

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[55] *Ibid.*, pp. 597-598.

[56] *Ibid.*, p. 634.

Explanation: The energy states of hydrogen can be successfully described by the combined picture of waves and particles.[57]

Textbook: Investigations in Physics[58]

Chapter 17. Abbreviated Concept: Electromagnetic waves and relativity.

Explanation of relativity concept: "One of the consequences of the theory of relativity is that if light acts like a wave, the wave travels in a medium that is physically undetectable."[59] The total energy, E, of a moving object is given by the equation $E = mc^2$ (m = relative mass, c = speed of light)."[60]

Chapter 19. Abbreviated Concept: Atomic models--Bohr; Shrodinger wave equations.

Explanation of Shrodinger wave equations: ". . . Shrodinger developed a mathematical model of the atom based on the wave properties of particles . . . Schrodinger's wave equation gives the probability that an electron will be located at a particular distance from the nucleus."[61]

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[57] Ibid., pp. 656-657.

[58] J. W. Renner, Investigations in Physics.

[59] Ibid., p. 484.

[60] Ibid., p. 480.

[61] Ibid., pp. 553-554.

Chapter 20. Abbreviated Concept; Nuclear models and particles.

Explanation: In the proton-electron nuclear model the nucleus is made up of discrete particles. There are sufficient protons in the nucleus to make the mass correct and there are sufficient electrons to make the charge correct.[62]

There are a large number of particles most of which can be explained by competing theories with varying degrees of success.[63]

Text: Physics: Teacher's Edition[64]

Chapter 15. Abbreviated Concept: Internal potential and kinetic energy.

Explanation of internal potential energy: "Substances with strong inter-molecular bonds have high heat capacities because a relatively large fraction of the heat energy supplied goes into increasing internal potential energy."[65]

Chapter 17. Abreviated Concept: Elementary electronic charge.

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[62] *Ibid.*, pp. 572-573.

[63] *Ibid.*, p. 594.

[64] I. Genzer, *Physics*.

[65] *Ibid.*, p. 415.

Explanation: ". . . there is a fundamental discrete unit of charge--an electron."[66]

Text: Project Physics: Text[67]

Chapter 17: Abbreviated Concept: Faraday's laws.

Explanation: ". . . Faraday's first law of electrolysis: the mass of an element released at an electrode during electrolysis is proportional to the amount of charge which has passed through the electrode. . . . His second law of electrolysis states: if A is the atomic mass of an element, and if v is valence, a transfer of 96,540 coulombs of electric charge releases A/v grams of the element."[68]

Chapter 19. Abbreviated Concept: Rutherford-Bohr model of the atom.

Explanation: "Bohr introduced two new postulates (i.e., to the Rutherford model) specifically to account for the existence of stable electron orbits and separate emission spectra . . . (For the hydrogen atom) the possible electron orbits are circular . . . and atoms exist only in definite energy states . . . Bohr's results for the possible stable orbit radii r_n was $r_n = an^2$ where a is a constant ($h^2/4\ ^2kmq^2$)

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[66] Ibid., p. 473.

[67] G. Holton, Project Physics.

[68] Ibid., p. 30.

which can be calculated from known physical values and n stands for any whole number 1, 2, 3, . . ."[69] (h = Planck's constant, k = Coulomb's constant, m = mass of electron, q = electronic charge).

Text: The World of Physics[70]

Chapter 1. Abbreviated Concept: Newton's third law of motion.

Explanation: "If two objects are exerting a force on each other, the force exerted by the first one on the second must be exactly equal in strength and opposite in direction to the force exerted by the second one on the first."[71]

Chapter 7. Abbreviated Concept: Conservation laws.

Explanation: "We say that a property of matter is conserved when it always stays the same even though other properties of the same piece of matter are changing. There are several different properties which are always conserved."[72] (e.g., magnetic and frictional forces).[73]

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[69] *Ibid*., pp. 73-75.

[70] R. Hulsizer, *The World of Physics*.

[71] *Ibid*., p. 10.

[72] *Ibid*., p. 170.

[73] *Ibid*., p. 243.

Chapter 10. Abbreviated Concept: Internal energy.

Explanation: "The energy contained within a system is designated that system's internal energy. This energy can be either potential or kinetic, or some mixture of the two."[74]

Chapter 12. Abbreviated Concept: First and second laws of thermodynamics.

Explanation: "The first law of thermodynamics, true for any system, is net heat added to system + net work done on system = net change in internal energy of system."[75] "In all reactions involving heat, if no outside work is done on a system, heat will flow in the direction which makes the total entropy of the system increase to its highest possible value . . . the second law of thermodynamics."[76]

Chapter 15. Abbreviated Concept: Properties of sound waves.

Explanation: "Sound is comprised of waves of compression we detect with our ears. These waves move through the air with certain frequencies."[77] "The properties of the medium affect the speed of sound."[78]

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[74] Ibid., p. 274.

[75] Ibid., p. 335.

[76] Ibid., pp. 336-337.

[77] Ibid., p. 422.

[78] Ibid., p. 427.

Text: Modern Physics[79]

Chapter 3. Abbreviated Concept: Resolution and composition of forces.

Explanation: "When two or more forces act concurrently at a point the resultant force is that single force applied at the same point that would produce the same effect."[80] "Resolution of force . . . is the separation of a single force into two or more component forces acting in given directions on the same point."[81]

Chapter 8. Abbreviated Concept: Thermal energy.

Explanation: "Thermal energy of a material (is) the total potential and kinetic energy associated with the random motion of its particles."[82]

Chapter 24. Abbreviated Concept: Radioactivity and nuclear reactions.

Explanation: "Radioactivity is the spontaneous uncontrollable decay of an atomic nucleus with the emission of particles and rays."[83] "In a nuclear change . . . new materials are formed by changes in the identity of the atoms themselves."[84]

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[79] J. Williams, Modern Physics.

[80] *Ibid.*, p. 53.

[81] *Ibid.*, p. 50.

[82] *Ibid.*, p. 173.

[83] *Ibid.*, p. 603.

[84] *Ibid.*, p. 606.